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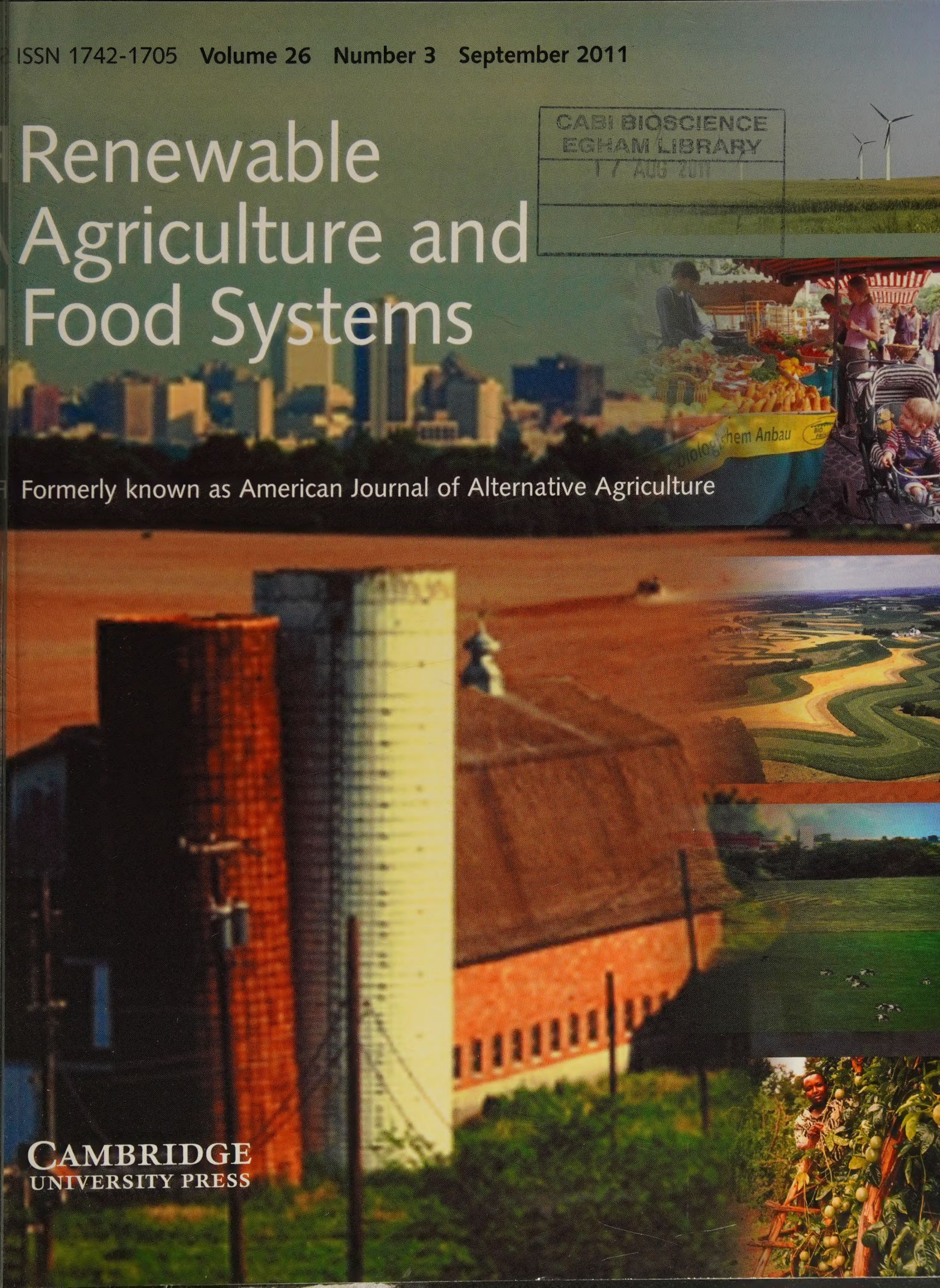

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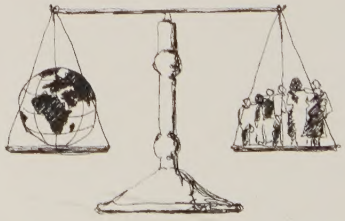

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Business opportunity assessment in Slovene organic spelt processing: application of real options model

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Abstract

Decision making in organic farming is related to risk and uncertainty, and options must be evaluated in the decision-making process. This paper presents the methodology of an integrated deterministic simulation system (KARSIM 1.0) application for decision-making support on organic farms in northeastern Slovenia. An emphasis to modify the net present value (NPV_t) criterion by incorporating the real options approach was made. Its application is shown in organic spelt (*Triticum aestivum* ssp. *spelta* McKey) production and processing using two real options approaches, the Black–Scholes and binomial models. The NPV_t indicates that the decision to process spelt for animal fodder is financially unfeasible, while the real options approach differentiates the results by organic spelt grain and flour production for human nutrition. It may be concluded that the real options approach can be useful when assessing projects with uncertainty, sunk costs and irreversibility, and it can provide for examining agricultural investment decisions.

Key words: farm decision making, binomial model, Black–Scholes model, net present value, organic spelt

Introduction

Farmers consistently face decisions about whether to invest in a new production method with increased risks and uncertainties or to maintain a current system without new risks and uncertainties. A possible method used to evaluate a new business or investment opportunity is the traditional discounted cash flow method[1,2]. Several researchers argue that the net present value (NPV_t) is not adequate under uncertain conditions and typically considers projects to be irreversible[3–6]. To evaluate suitable investment possibilities, an investor-farmer needs to take into account the value of keeping options open, including the impact of sources of uncertainty and risk attitudes. The risk and uncertainty associated with management decisions are included in the formulation of real options problems[5,7] and real option models[8]. Theoretical advances in real options methodology have been formulated and assimilated in several empirical applications[9–11] and studies on the application of real options in agriculture are emerging[12–17].

In this paper, the use of the decision-making process and its tools for evaluating investments in organic spelt-processing business alternatives using elements of the real options methodology is presented. The study focuses on the impact of NPV_t as a parameter for investment decisions in the framework of cost benefit analysis (CBA) and the real options model (Black–Scholes (BS) and binomial models).

This paper is organized as follows. The theoretical background of the applied methodology is followed by a presentation of its application in a case study. In the results section, individual business alternatives for organic spelt processing are presented and discussed. Finally, the paper highlights the importance of incorporating the real options approach in agricultural investment evaluations and implications for decision making on the farm.

Case study

In this paper, the application of the presented methodology in the context of organic farming is presented. Organic farming is becoming more and more popular among Slovene farmers, especially in the observed region. At the beginning of 2009, the number of farms practicing organic farming exclusively or taking up organic farming systems amounted to more than 2.096 or 2.68% of all farms in Slovenia[18]. A few larger organic farms from this region

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specialize in grain production (i.e., wheat, rye, maize, barley, millet, oats and spelt). However, the level of organic farm income is closely linked to the exploitation of various new business opportunities. Spelt wheat planting (*Triticum aestivum* ssp. *spelta* McKey), already included in northeastern Slovenia crop rotations, appears more on small (< 5 ha of arable land) and mixed organic farms, due to its high resistance to diseases and low input of nitrogen.

From another perspective, spelt wheat can be directly processed into different kinds of food products on the farm itself and represents additional business and market opportunities for organic farmers. The case study involves spelt production and processing for animal fodder, which is a real option for undertaking production and marketing of two products important in human nutrition – husked spelt grain and spelt flour. A small organic part-time farm (4 ha of arable land) in northeastern Slovenia was considered in order to compare spelt-processing investment projects using the methodological approach presented. The farm regularly includes other grains in addition to spelt wheat in its crop rotation. The annual area of spelt wheat is, according to crop rotation rules, limited to 1 ha with an average yield of 2500 kg unhusked spelt grain. The service of husking and milling the grain is outsourced by the farmer. He uses the spelt for animal fodder, but the alternative option considered in this model is to sell spelt grain and spelt flour to individual customers. However, spelt-processing investment projects are related to risk and uncertainty, and the proposed investment projects must be analyzed before their implementation. Based on a literature review, the real option analysis is recognized as a suitable tool in order to conduct such an analysis.

A *real option* is defined as the value of being able to choose some characteristic of a decision with irreversible consequences (sunk costs for investments), which especially affects financial income. Real option uses a flexible approach to uncertainty (i.e., ecological and technological production possibilities, economic efficiency of production, market and trade opportunity) by identifying its sources, developing future business alternatives and constructing decision rules. It attempts to reduce risk by monitoring the implementation of its decisions and requiring decision making to be adaptive throughout the life cycle of a project.

Thus, the case study examines aforementioned three options using the real option approach.

Materials and Methods

The methodological framework for the financial and real option approach assessment of spelt-processing alternatives lies within the interrelation of the spelt-processing simulation model, KARSIM 1.0[1]. The first presented technique, CBA, is one of the common methodological approaches to farm management, while the real options approach is based on the BS and binomial models.

KARSIM 1.0 integrated deterministic simulation model

Simulation modeling can be efficiently applied in both cost-estimation and cost-benefit analyses[19,20]. Furthermore, simulation represents one of the fundamental tools for making management decisions[21]. The computer simulation model, KARSIM 1.0, was developed for the financial and technological analysis of food processing (in the case of Slovene farms). This model consists of 74 production and food-processing submodels. The spelt-processing options are included within the KARSIM 1.0 model as four individual submodels: spelt husking, spelt flour, spelt cookies and spelt bread. Every submodel consists of a calculation of both investment and production costs. The system as a whole represents a complex calculation system and each submodel results in a specific enterprise budget. Through a special interface, the system enables simulation of different business alternatives at the farm level. Furthermore, based on enterprise budgets, cash-flow projections can be conducted together with the investment costs for each business alternative, and the NPV_t for each simulated alternative can be computed. All iterations (calculations for individual alternatives) are saved into a database, which is then used as one of the data sources for further analysis and assessment. The KARSIM model has been described in detail in our previous research[1].

Traditional NPV_t analysis versus the real options approach

The decision as to which spelt-processing method to undertake on an individual farm is rarely made on the basis of NPV_t calculation alone. At this point, the real options methodology can be introduced into the planning process where some further KARSIM 1.0 results represent input variables for BS and binomial model analyses. The preferred approach to evaluating investments is NPV_t analysis. For an investment of t periods, the formula is $NPV_t = -I + \Sigma TR - TC/(1+r)^t$, where NPV_t is the net present value (€), I is the investment costs (€), TR is the total revenue (€), TC is the total costs (€), r is the interest rate (%) and t is the time (number of years)[7].

By isolating the cash costs from the enterprise budget, the annual cash flow is estimated, representing a basic input parameter for the computation of NPV_t. In the NPV_t equation, the aggregate benefits TR and the aggregate costs TC are annually summed and discounted to the present with the selected discount rate r.

In the following section, the concept of options will be introduced to show how the real options approach can be appended to the basic NPV_t model. The real options approach has become an increasingly standard framework for investment-timing decisions[22].

BS model

To illustrate the real options of methodology, the BS model and the binomial model for organic spelt-processing business alternatives were developed. *Real option* describes an option to buy or sell an investment in physical or intangible assets rather than in financial assets. Thus, any corporate investment in plant, equipment, land, patents and brand names, for example, can represent the assets on which real options are written. In addition, investments can be evaluated as real options, and can be treated analogically. The value of real options is described by the best-known Black–Scholes option model (BSOPM)[23]. The BSOPM, based on stochastic calculus, is shown below:

$$OV = SN(d_1) - X/e^{-rt} N(d_2)$$

$$d_1 = \left[\ln(S/X) + (r_f + 1/2\sigma^2)^* t\right]/\sigma\sqrt{t}$$

$$d_2 = d_1 - \sigma\sqrt{t}$$

where OV is the option value (€), S is the present value of cash flows from optional investment (€), d_1 is the log–normal distribution of $N(d_1)$, d_2 is the log–normal distribution of $N(d_2)$, X is the investment expenditure (€), r_f is the annual risk-free continuously compounded rate (%), σ is the annualized variance (risk) of the investment's project, t is the period until investment (years) and e^{-rt} is the exponential term (2.71828). The real options method explicitly accounts for uncertainty in the determination of an optimal decision in light of the stochasticity of an asset's value (e.g., the organic spelt grain quantity and quality production and consequently the available option results depending on many parameters). Some of them could be defined as stochastic parameters: technological parameters or input material (e.g., the efficiency of organic farming allowed specific fertilizer and substances for crop resistance and protection depends on environmental and ecological conditions of the observed region, the suitability of a seed variety or different unexpected market parameters); unexpected ecological conditions (such as weather, new pests, supply and demand concepts and consumer preferences). Further, spelt flour production is more complicated and risky; beyond the above-mentioned parameters, spelt flour production has very important technical parameters as well (e.g., grain-processing technology and storage conditions). The stochastic variable in calculus is expressed in the concept of annual, risk-free, continuously compounded rates and annualized variance (risk) of the investment's project. In the present case, some stochastic variables could also be defined as risk and uncertainty variables. For example, the agriculture policy plays an important role in organic spelt grain production at this moment. Using the corresponding financial instruments, the agriculture policy supports Slovene farmer spelt grain production (with subsidies). The abrogation of the above-mentioned instrument could cause uncertainty in organic spelt production:

Option value OV=$SN(d_1)$ – present value of X times $N(d_2)$

where $N(d_1)$ and $N(d_2)$ represent probability distributions. The values of $N(d_1)$ and $N(d_2)$ are obtained from normal probability distribution tables. They give us the probability that S or X will be below d_1 and d_2. In the BS model, they measure the risk associated with the volatility of the value of S.

However, the strategic real options of the investment project are calculated using the BS methodology as follows:

$$NPV_{SRO} = NPV_t + OV,$$

where NPV_{SRO} is the strategic real option (€). The strategic real options and BS models are seldom used in agricultural practice. To explicate the applicability of NPV_{SRO} and BSOPM models in agricultural investments and present the results, a case study was performed.

The binomial model

The binomial option-pricing model is currently the most widely used real options valuation method. The binomial model (i.e., lattice) describes price movements over time, where the asset value can move to one of the two possible prices with associated probabilities. The binomial model is based on a replicating portfolio that combines risk-free borrowing (lending) with the underlying asset to create the same cash flow as the option. Since an option represents the right but not the obligation to make an investment, the payoff scheme for the option is asymmetric. The analysis performed in this work makes use of the multiplicative binomial model of Cox and Rubinstein[24] the standard tool for option pricing in discrete time.

The binomial model methodological background can be presented by node of value NPV_t that can lead to two nodes with their values being given by NPV_t with probability $1+d=d_1$ and $1-d=d_2$, respectively. The probability of reaching each of these nodes is the usual equivalent Martingale measure used in the binomial option pricing model of Cox and Rubinstein[24]: $d_1 = (1+r_f)-d/u-d$ and $d_2 = 1-d_1$, where r_f is the risk-free rate over the interval dt, $u = \exp(\sigma\sqrt{dt})$ and $d = \exp(-\sigma\sqrt{dt})$. It should be noted that as $dt \to 0$ the variables of the multiplicative binomial process converge to the geometric Brownian motion. At each step, the price moves up or down by an amount obtained from its volatility, which is assumed to be constant and known, and the time step length. Thus, the lattice provides a representation of all possible demand values throughout the whole project life[9]. The investment project option value (OV) could be calculated using the backward induction process[25,26].

Results and discussion

The identified business alternatives are evaluated using specially developed simulation models in an Excel spreadsheet environment. Basic simulation model production data

Table 1. Results for planned spelt-processing projects.

Business alternative	Product quantity (kg)	Total costs (€)	Total revenue (€)	Coefficient of economics
Husked spelt (animal fodder)	1470	504	779	1.54
Spelt grain (human nutrition)	1470	1238	3675	2.97
Spelt flour	1176	1405	3293	2.34

Note: Product quantity is the product quantity (kg) produced or processed at organic farm; total costs is the sum of fixed and variable product cost in €; total revenue is the product of product quantity (kg) and price (€); coefficient of economics is the quotient between total revenue (€) and total costs (€).

Table 2. CBA analysis results of planned spelt-processing projects t (after 5 years and discount rate = 10%).

Product	I (€)	Annual cash flow (€)	NPV_t (€)	P_d (years)
Spelt grain (animal fodder)	2092.05	237.24	−1192.74	23
Spelt grain (human nutrition)	2092.05	2550.08	7574.00	1
Spelt flour	2092.05	1989.03	5447.92	2

Note: I is the investment costs (€); annual cash flow (€) is the difference between total revenue (€) and total costs (€); NPV_t is the net present value (€); P_d is the investment return period (years); discount rate is the 10% (in this paper, the interest rate as discount rate was used for the CBA analysis; to adjust for risk or other factors it is appropriate to use higher value of discount rate).

and calculated economical variables for individual business alternatives are presented in Table 1.

Based on discounted cash flow methodology, the traditional NPV_t criterion is used extensively in assessing an investment opportunity for three analyzed spelt products (Table 1). The results are calculated with the assumption that the product sells successfully at the expected prices. The estimated production levels were calculated on the basis of the annual spelt production area. As shown in Table 2, CBA analysis shows positive NPV_t for spelt processed for human nutrition (spelt grain and spelt flour). The highest NPV_t was observed for husked spelt grain ($NPV_t = 7574.00$ €). The lowest NPV_t was calculated for spelt grain for animal nutrition. Its market price is lower compared to that of husked spelt grain for human nutrition; however, the basic production costs are the same as for processed spelt grain. The investment return period (P_d) is the lowest for husked spelt grain, followed by that of spelt flour.

The results of traditional CBA show financial feasibility for spelt grain (human nutrition, $NPV_t = 7574.00$ €) and spelt flour ($NPV_t = 5447.92$ €). As expected, investment in spelt grain for animal fodder is financially unfeasible ($NPV_t = -1192.74$ €), and the investment return period is unsuitable. The results of the traditional NPV_t for spelt grain production (animal fodder, $NPV_t = -1192.74$ €) presents the base for calculation of the strategic real option of spelt grain and spelt flour (for human nutrition). However, the results of the real options approach show a more favorable picture from the farmer's perspective. The risk-free rate and variance of the project's investment were defined as deterministic (between input model variables existing in a fixed cause–consequence relation, expressed in mathematical form). To illustrate the real options methodology, we present two examples of our real options model output. In the first part of Table 3, the variables used in the real options model calculation for the spelt grain and spelt flour production are demonstrated. The second part of Tables 4 and 5 show calculated simulation model results for real options' calculation.

As seen in Table 3, the OV for husked spelt grain, calculated by BS methodology, is 1370.91 €. The results of the application of the BS methodology by analyzed farm business alternatives show the interest in the investment project ($NPV_{SRO} = 178.17$ €). Further, the results of analyzed farm business alternatives (spelt flour) indicate that the calculated OV is 875.34 €. According to the OV calculation, the strategic real option of spelt grain for animal nutrition and further processing into spelt flour is a lower value, and in the analyzed case, a negative value (−317.40 €). The result shows that the spelt flour production option is unsuitable for the farmer. On the basis of data calculated with the BS methodology, it can be concluded that the second business alternative (spelt flour) for the farmer is not the most appropriate option. Further, project investment option values are calculated using the binomial lattice. The results show that financially the most interesting and suitable investment is spelt grain production, where the option value results in a value of 1370.91 €, followed by spelt flour production (878.33 €). As expected, spelt grain production for animal nutrition is for the decision maker (i.e., the farmer), the worst alternative (OV = 0.0 €). All binomial model results are calculated under the assumption that calculated $d_1 = 1.350$, $d_2 = 0.741$ and $P = 0.598$. The detailed presentation of the binomial lattice calculations is given in Table 4. Table 5 shows more results for spelt grain production for human nutrition.

It should be mentioned that between both option model results exist low differences in the individual alternative assessments. In preliminary CBA results, the unsuitable investments in spelt grain production for animal nutrition could be seen already by CBA analysis, where

Table 3. Descriptions and values of variables for the real options model for spelt grain (human nutrition) and spelt flour.

Variable description	Spelt grain (human nutrition) value	Spelt flour value
Present value of cash flow from optional investment	2550.08 €	1989.03 €
Investment expenditure	2092.05 €	2092.05 €
Exponential function	2.71828	2.71828
Risk-free rate	10%	10%
Period until investment (years)	5	5
Variance (risk) of the project investment	30%	30%
d_1	1.375899776	1.005485973
d_2	0.705079382	0.33466558
Log–normal distribution of d_1	0.915573668	0.84266855
Log–normal distribution of d_2	0.759619582	0.631061315
Option value of	1370.91 €	875.34 €
Strategic real option of spelt grain for animal nutrition	(... processing of spelt grain for human nutrition) 178.17 €	(... processing of spelt flour) −317.40 €

Table 4. Investment evaluation matrices for spelt grain for human nutrition.

Time (years)	0	1	2	3	4	5
NPV_t (€)	2550.08	3442.25	4646.56	6272.19	8466.58	11,428.68
		1889.15	2550.08	3442.25	4646.56	6272.19
			1399.52	1889.15	2550.08	3442.25
				1036.79	1399.52	1889.15
					768.07	1036.79
						569.00

Note: NPV_t, net present value (€).

Table 5. Option value results for spelt processing (spelt grain for human nutrition).

Time (years)	0	1	2	3	4	5
OV (€)	1369.30	2079.44	3106.47	4559.37	6573.61	9336.63
		670.31	1094.49	1756.24	2753.59	4180.14
			241.16	395.63	730.88	1350.20
				0.00	0.00	0.00
					0.00	0.00
						0.00

Note: OV, option value (€).

$NPV_t = -1192.74$ € (Table 2). However, the option models further confirm the preliminary CBA results (Tables 2 and 5).

Conclusions

The application of the discount cash flow approach in agriculture is not always the appropriate way to decide whether an investment project is feasible or not. In this work, an attempt was made to employ a real options approach to evaluate the spelt-processing business alternatives on an organic farm. The general implication of this empirical analysis is that risk and uncertainty play an important role in the farmer's decision to adopt a new organic spelt-processing business alternative that is more appropriate and feasible for the farm. Empirical results confirm that the production of spelt grain (for human nutrition) versus spelt flour is superior for the analyzed farm. However, BS methodology could be widely used in agricultural practice too, since it is easy to calculate and it explicitly models the relationship of all the variables. The model results are often useful in practice and helpful in setting up hedges in the correct proportions to minimize risk. Even when the results are not completely accurate, they serve as a first approximation to which adjustments can be made.

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Soil fertility and the yield response to the System of Rice Intensification

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Abstract

The System of Rice Intensification (SRI) is a low-input rice (*Oryza sativa* L.) production system that differs from conventional systems in several ways: seedlings are transplanted earlier and are more widely spaced, organic fertilizer is often used in addition to mineral fertilizer, and soils are irrigated intermittently rather than flooded for long periods. The yield benefits of SRI compared to conventional systems can be substantial, and yet are regionally variable and have been the subject of considerable debate, due partly to a lack of mechanistic understanding. Here we show that soil properties may in part explain the variability in yield response to SRI. A meta-analysis of data from 72 field studies where SRI was compared with conventional systems indicates that yields increased significantly ($P < 0.0001$) when SRI was implemented on highly weathered infertile soils rich in iron and aluminum oxides (Acrisols and Ferralsols), but there was no difference in yield between SRI and conventional systems in more fertile favorable soils for rice production (Gleysols, Luvisols and Fluvisols). The yield difference between SRI and conventional rice production therefore appears to be related in part to soil properties linked to weathering. This should help resolve the debate about the value of SRI and allow research to be targeted toward understanding the biological and chemical processes in soils under SRI management.

Key words: System of Rice Intensification, highly weathered soils, marginal soils, low-input rice production

Introduction

Rice (*Oryza sativa* L.) is the staple food for more than half of the world's population, and yet by 2030, global rice production must double to meet demand[1], placing greater stress on already threatened land and water resources. The rising costs of fertilizers produced using fossil fuel, agricultural inputs and transportation also contribute to the increasing food insecurity in rice-dependent areas. To meet future rice demand while preserving environmental resources, new low-input solutions that can lead to stable, locally produced rice supplies are necessary[2].

The System of Rice Intensification (SRI) has been used as a method to increase yield and reduce water and mineral fertilizer consumption[3,4]. Developed in Madagascar in the 1980s, SRI was adopted in parts of Asia during the early 1990s, and more recently in Africa and Latin America. The SRI method relies on early transplanting, wide row spacing, organic fertilizer use and intermittent wetting and drying of the soil rather than the prolonged flooding practiced in conventional rice paddy systems[5]. Most SRI studies so far have involved small field trials comparing SRI methods with conventional methods of rice cultivation. Yield differences between the SRI and conventional system are highly variable and the potential of SRI has therefore been debated at length in the peer-reviewed literature[6–13]. Proponents claim that SRI increases the physiological yield potential of rice, which can increase yield by 50–100%. The 'SRI controversy' stemmed from reports of SRI yields in Madagascar as high as 20 t ha^{-1}. These yields were considered to be erroneous based on theoretical models of the photosynthetic capabilities of rice and led to major criticism of SRI in general from the rice research community[9,10,13]. Critics argue that yield increases reported with SRI were related to a decline in iron toxicity to rice plants and restricted to the highly ferralitic soils of Madagascar[11]. A previous meta-analysis of 40 studies comparing SRI with the conventional system concluded that SRI had no potential to increase yields outside of Madagascar[11]. However, these authors reported yield differences ranging from a 22% yield increase to a 61% yield decrease with SRI in regions outside Madagascar; they did not provide an explanation for the wide variability in yield response to SRI[11].

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Table 1. Soil types, soil fertility group and rice yields from field experiments where SRI was evaluated against the conventional method. The yield difference was calculated as SRI Yield – Conventional Yield and the ln RR was ln(SRI Yield/Conventional Yield).

Location	Soil type (FAO)	Soil fertility group	SRI yield t ha^{-1}	Conventional yield	Yield difference	ln RR
Madagascar (Anjomakely)[25]	Ferralic Cambisol	Low	10.4	3.0	7.4	1.24
Madagascar (Anjomakely)[25]	Ferralic Cambisol	Low	6.4	2.0	4.4	1.14
Myanmar (Kachin)[36]	Orthic Acrisol	Low	6.4	2.1	4.3	1.11
Gambia (Sapu)[37]	Gleyic Luvisol	Moderate	5.3	1.8	3.5	1.07
Madagascar (Morondova)[25]	Ferralic Cambisol	Low	6.0	2.1	3.9	1.04
Madagascar (Morondova)[25]	Ferralic Cambisol	Low	6.8	2.8	4.0	0.88
Nigeria (Sabongida)[38]	Eutric Regosol	Moderate	5.8	2.9	2.9	0.69
Indonesia (Central Sulawesi)[39]	Orthic Acrisol	Low	7.1	3.8	3.3	0.62
India (Uttarakahan)[40]	Dystric Cambisol	Low	5.2	2.8	2.4	0.62
Indonesia (South Sulawesi)[39]	Orthic Luvisol	Low	7.8	4.3	3.5	0.61
India (Hamchal Pradesh)[40]	Dystric Cambisol	Low	5.3	2.9	2.4	0.60
Indonesia (Nusa Tengarra)[39]	Orthic Acrisol	Low	6.6	3.6	3.0	0.60
Iran (Mazandaran)[41]	Calcic Cambisols	Moderate	8.8	5.6	3.2	0.45
Indonesia (Sukamandi)[42]	Orthic Acrisol	Low	7.5	4.9	2.6	0.43
Indonesia (West Sumatra)[42]	Dystric Fluvisol	Low	5.3	3.5	1.8	0.41
India (Balrampur)[15]	Dystric Cambisol	Low	6.3	4.2	2.1	0.40
Indonesia (Sukamandi)[42]	Orthic Acrisol	Low	6.9	4.7	2.2	0.38
India (Orissa)[18]	Orthic Acrisol	Low	6.4	4.5	1.9	0.35
Indonesia (Sukamandi)[42]	Orthic Acrisol	Low	7.7	5.5	2.2	0.33
China (Hangzhou)[19]	Eutric Gleysol	High	7.1	5.1	2.0	0.33
Indonesia (West Nusa Tenggara)[42]	Vertic Luvisol	Moderate	5.9	4.3	1.6	0.32
Indonesia (Sukamandi)[42]	Orthic Acrisol	Low	7.7	5.7	2.0	0.30
Indonesia (Sukamandi)[42]	Orthic Acrisol	Low	8.3	6.4	1.9	0.26
Bangladesh (Burichang)[43]	Eutric Gleysol	High	7.0	5.4	1.6	0.26
Indonesia (Sukamandi)[42]	Orthic Acrisol	Low	8.4	6.5	1.9	0.25
Indonesia (Sukamandi)[42]	Orthic Acrisol	Low	8.4	6.5	1.9	0.25
Madagascar (Beforona)[3]	Xanthic Ferralsol	Low	6.3	4.9	1.3	0.24
Indonesia (Bali)[42]	Ochric Andosol	Moderate	7.3	5.7	1.6	0.24
Indonesia (West Nusa Tenggara)[42]	Vertic Luvisol	Moderate	7.1	5.7	1.4	0.22
Indonesia (West Sumatra)[42]	Dystric Fluvisol	Low	4.7	3.8	0.9	0.21
Indonesia (South Sulawesi)[42]	Vertic Luvisol	Moderate	8.0	6.5	1.5	0.21
India (Coimbatore)[16]	Pellic Vertisol	Moderate	7.0	5.7	1.3	0.20
Laos (Pakcheng)[44]	Orthic Acrisol	Low	5.6	4.6	1.0	0.20
Indonesia (East Java)[42]	Vitric Andosol	Moderate	8.9	7.4	1.6	0.19
Indonesia (North Sumatra)[42]	Dystric Fluvisol	Low	6.1	5.0	1.1	0.19
Bangladesh (Comilla)[22]	Eutric Gleysol	High	5.3	4.4	0.9	0.19
India (Pondicherry)[24]	Dystric Regosol	Low	6.4	5.4	1.0	0.18
China (Yantze River)[23]	Eutric Gleysol	High	12.2	10.2	2.0	0.17
Indonesia (Central Java)[42]	Mollic Andosol	Moderate	7.0	5.9	1.1	0.16
Laos (Vientiane)[44]	Gleyic Acrisol	Low	7.5	6.5	1.0	0.15
Indonesia (West Nusa Tenggara)[42]	Eutric Fluvisol	High	7.4	6.5	0.9	0.13
Bangladesh (Debidwar)[43]	Eutric Gleysol	High	7.0	6.2	0.9	0.13
Thailand (Chiang Mai)[27]	Orthic Acrisol	Low	2.3	2.1	0.3	0.11
Indonesia (South Sulawesi)[42]	Orthic Luvisol	Moderate	6.5	5.8	0.7	0.11
India (Jhalda)[15]	Ferric Luvisol	Low	4.2	3.8	0.4	0.11
Sri Lanka (Hinguraggoda)[26]	Chromic Luvisol	Moderate	7.6	6.9	0.7	0.10
Laos (Phonengam)[44]	Gleyic Acrisol	High	3.6	3.3	0.3	0.09
China (Jiangsu)[45]	Calcaric Gleysol	High	9.9	9.1	0.8	0.08
Iraq (Najaf)[46]	Calcaric Fluvisol	High	5.5	5.1	0.3	0.07
Indonesia (Central Java)[42]	Pellic Vertisol	Moderate	8.0	7.6	0.4	0.05
China (Jiangsu)[45]	Eutric Gleysol	High	9.3	9.1	0.3	0.03
China (Nanjing)[45]	Eutric Gleysol	High	11.7	11.5	0.3	0.02
Indonesia (West Java)[42]	Dystric Nitosol	Low	5.5	5.4	0.1	0.02
China (Guangdong)[10]	Eutric Gleysol	High	7.2	7.2	−0.1	−0.01
China (Nanjing)[45]	Eutric Gleysol	High	7.8	8.3	−0.5	−0.06

Table 1 (Continued)

Location	Soil type (FAO)	Soil fertility group	SRI yield t ha^{-1}	Conventional yield	Yield difference	ln RR
Nepal (Bhairahawa)[47]	Dystric Regosol	Low	5.4	5.7	−0.3	−0.06
China (Jiangyin)[45]	Eutric Gleysol	High	8.4	8.9	−0.5	−0.06
Bangladesh (Comilla)[17]	Eutric Gleysol	High	7.1	7.6	−0.5	−0.07
China (Nanjing)[45]	Eutric Gleysol	High	9.8	10.6	−0.7	−0.07
Ivory Coast (M'be)[48]	Ferric Acrisols	Low	3.7	4.0	−0.3	−0.08
China (Hunan)[10]	Eutric Gleysol	High	6.7	7.4	−0.7	−0.10
Thailand (Chiang Mai)[27]	Orthic Acrisol	Low	4.4	4.8	−0.5	−0.10
Bangladesh (Vangurapara)[17]	Eutric Gleysol	High	6.0	6.8	−0.8	−0.12
Laos (Vientiane)[44]	Gleyic Acrisol	Low	4.1	4.7	−0.6	−0.14
Bangladesh (Matiara)[17]	Eutric Gleysol	High	5.9	7.0	−1.1	−0.17
Philippines (Los Banos)[49]	Orthic Luvisol	Moderate	3.0	4.1	−1.1	−0.30
Laos (Savannakhet)[44]	Ferric Acrisol	Low	3.9	5.7	−1.8	−0.38
Indonesia (East Java)[42]	Vitric Andosol	Moderate	8.0	12.5	−4.5	−0.45
Thailand (Chiang Mai)[27]	Orthic Acrisol	Low	2.6	4.2	−1.6	−0.47
Thailand (Mae Taeng)[27]	Orthic Acrisol	Low	3.2	5.1	−2.0	−0.48
Thailand (San Sai)[27]	Eutric Fluvisol	High	3.3	5.4	−2.1	−0.48
Philippines (Los Banos)[49]	Orthic Luvisol	Moderate	1.4	3.1	−1.7	−0.77
	Mean		6.5	5.5	1.1	0.20
	Standard error		0.2	0.3	0.2	0.05

Some researchers suggest that SRI has the potential to increase yield in marginal soils with low nutrient availability and low potential for rice production, but has little potential to increase yields in more favorable soils where rice is already grown near the yield potential[12,13]. This seems likely, because soil biological contributions to soil fertility and improved microbial turnover of organic phosphorus under aerobic soil conditions may be more important in highly weathered low-fertility soils where phosphorus is often the limiting nutrient to crop production[4,14].

The objective of this study was to determine (1) whether SRI has a positive effect on rice yields in regions other than Madagascar and (2) if soil fertility can explain some of the regional variability in yield response to SRI management.

Materials and Methods

We collected yield data on SRI experiments and trials from peer-reviewed and non-peer-reviewed publications, reports and conference proceedings ($n = 72$, Table 1). Only data that fulfilled the following criteria were retained for analysis: (1) the SRI treatment used intermittent flooding and drying and an early planting date (rice seedlings were less than 15 days old at transplanting), whereas the conventional treatment had continuously flooded soils and a later planting date (seedlings were more than 20 days old at transplanting); (2) the SRI and conventional treatments were grown in the same season and the same location; and (3) each treatment was replicated at least thrice during the study. In total, 81 SRI–Conventional system comparisons were collected; 72 were included and 9 were not included because they did not meet the criteria outlined above. Of the 40 data points used in the previous analysis by McDonald et al. (2006), 29 were included and 11 were not included because they did not meet the previously stated criteria ($n = 5$) or they were cited as personal communication. Treatment means (Table 1) were the average yield of each rice variety when replicated plots existed at a single site. In studies testing several varieties, values in Table 1 represent the average yield of all varieties grown at a site or the average yield of varieties grown on multiple farms in the same farming area. We chose to include studies that had not been peer-reviewed since there were only six peer-reviewed studies available at the time[10,15–19]. So far, SRI has been mainly a grass-roots agricultural movement and there have been only a limited number of studies at major research institutions; most of the existing reports on SRI therefore come from local non-governmental and agricultural organizations. Given the stringent criteria for the inclusion of data in this analysis, we feel that the data set is strengthened by including non-peer-reviewed sources, which allows us to examine the effects of SRI on rice yield over a broader range of geographic regions and soil types.

Most studies did not provide information on soil properties, and so the soil type at each site was determined by entering the latitude and longitude into the ISRIC-WISE global data set of derived soil properties on a 0.5 by 0.5 degree grid using ARC-GIS software. Soils were then grouped on the basis of their fertility and potential for rice production[20,21]. Low-fertility soils were highly weathered soils rich in iron and aluminum oxides, namely Acrisols,

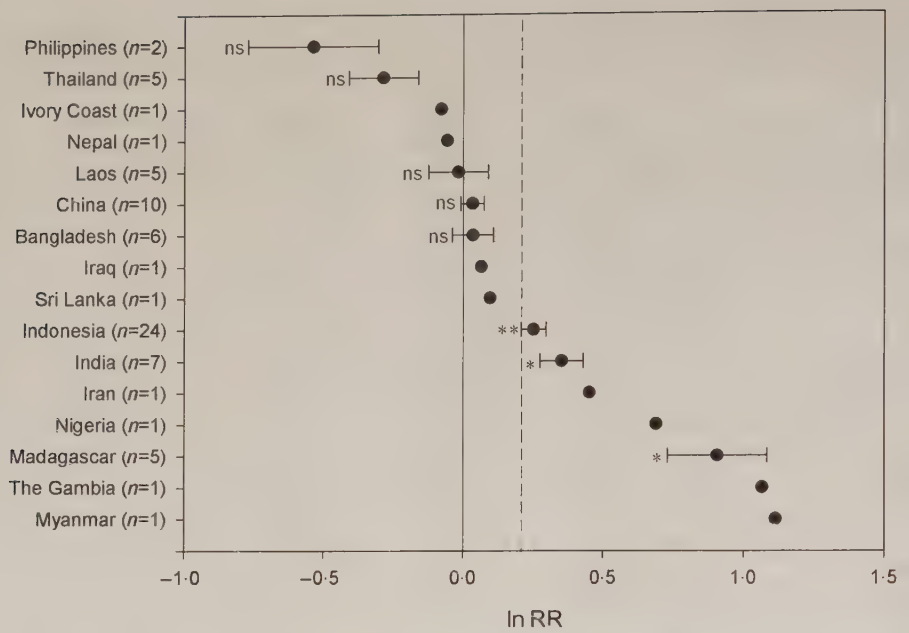

Figure 1. The ln RR of rice yield in SRI and conventional systems grouped by country. The mean ln RR and standard error are shown for countries with more than two data points. A reference line is shown at zero (——) and the mean ln RR of the complete data set (---) ($n = 72$) and its 95% confidence intervals (.....) are shown. The significance of each mean from zero is shown (t-test; *, $\alpha < 0.05$; **$\alpha < 0.001$; ns, not significant).

Ferralsols and Dystric Cambisols. The moderate-fertility soils (Andisols, Luvisols, Regisols, Vertisols and Cambisols) were moderately weathered soils with a greater potential for agricultural production. Young alluvial soils and soils considered ideal for rice production (Fluvisols and Gleysols) were classified as having high fertility. While there is some uncertainty associated with using this general system of soil identification and grouping, we consider it a necessary tradeoff in taking the first step to examine the relationship between soil fertility and yield response to SRI at the global scale using the currently existing data. The soil types determined by the ISRIC map were compared with the soils information available from 22 field studies to validate the accuracy of the predicted soil types[3,16,17,22–27].

The effect size of SRI management was calculated as the natural logarithm of the response ratio (ln RR) of SRI yield to conventional yield:

$$\ln RR = \ln(X/Y)$$

where X is the yield under SRI management and Y is the yield under conventional management[28]. The response ratio is commonly used to describe the effect size in meta-analyses testing the response of a treatment. The effect size, expressed as the ln RR, was positive when SRI produced greater rice yield than the conventional system and negative when there was lower yield in SRI than the conventional system. The ln RR is appropriate for meta-analysis because it provides a dimensionless measure of effect sizes that can be used to compare among studies[28]. The normality of the data was confirmed by examining Q–Q plots and using the Shapiro–Wilk test ($\alpha < 0.5$). Simple statistics (mean and t-test) were used to describe the performance of SRI relative to the conventional system in countries with more than two data points. The effect of soil fertility (low, moderate and high) on the ln RR was evaluated using the ANOVA procedure of SPSS statistical software (SPSS version 15.0, Chicago, IL). The model (ln RR = soil fertility group) indicated a significant ($P < 0.05$) effect of soil fertility, and so a post-hoc mean separation test was performed (least significant difference (LSD), $\alpha = 0.05$).

Results and Discussion

The results of 72 field trials comparing SRI and conventional rice production systems are summarized in Table 1. Overall, the mean ln RR was 0.20 and the 95% confidence interval ranged from 0.11 to 0.29, indicating that SRI had a positive effect on rice yields. Yield responses were grouped by country to determine if there were regions outside of Madagascar where SRI may have a positive effect on yield. The ln RR ranged from −0.54 in the Philippines to 1.11 in Myanmar (Fig. 1). The ln RR in Indonesia, India and Madagascar were significantly greater than zero, indicating a yield benefit from SRI compared to the conventional system (Fig. 1). Other countries with positive ln RR values were Iraq, Sri Lanka, Iran, Nigeria, Gambia and Myanmar (Fig. 1). The ln RR in studies from Thailand, Laos, China and Bangladesh did not differ significantly from zero, indicating no detectable difference in rice yield between SRI and conventional systems in these countries (Fig. 1).

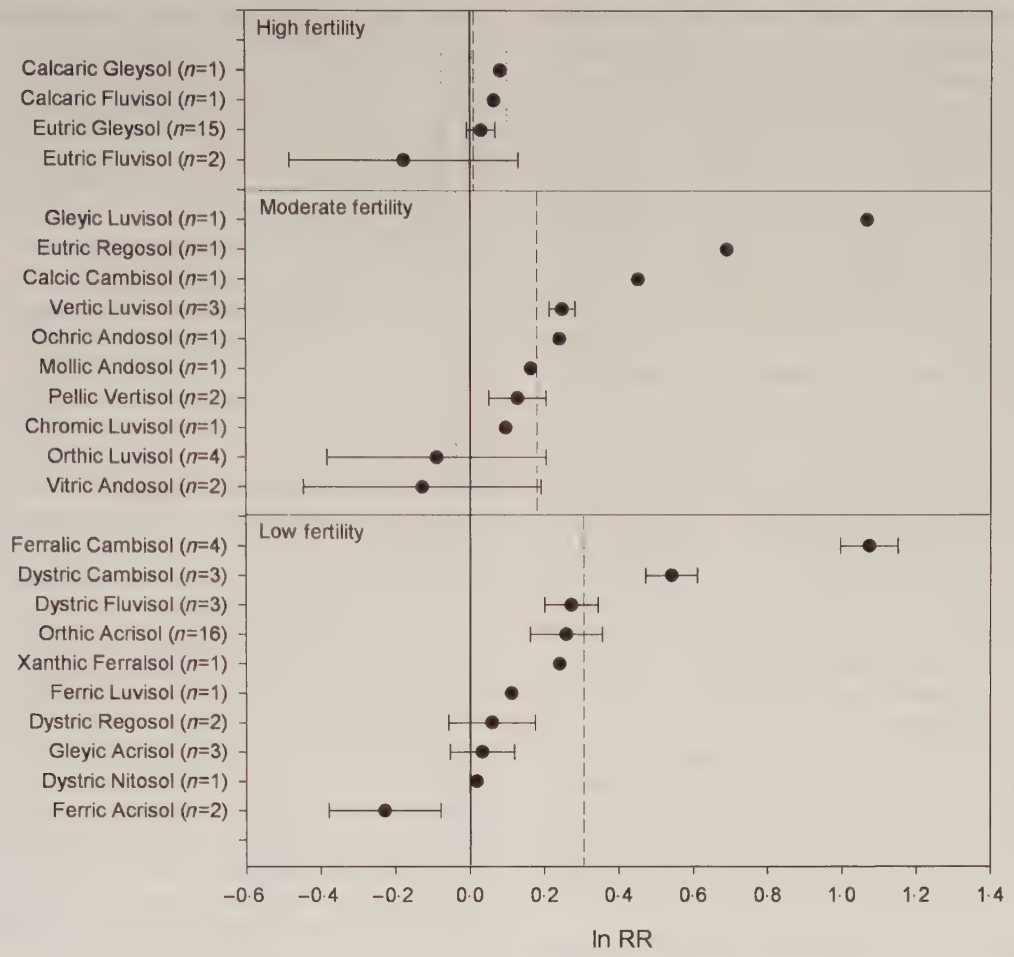

Figure 2. The ln RR of rice yield in SRI and conventional systems. Values are the mean and standard error for each soil type. Soils were assigned to fertility groups, namely high ($n = 19$), moderate ($n = 17$) and low ($n = 36$) fertility. A reference line is shown at zero (——) and mean ln RR (---) and 95% confidence intervals (.....) are shown for each soil fertility group.

A previous meta-analysis of 40 SRI trials concluded that SRI had no significant positive effect on yields in countries other than Madagascar[11]. The current study presents meta-analysis of a larger data set (72 SRI trials) and demonstrates that there are countries other than Madagascar, namely India and Indonesia, where SRI has a significant, positive effect on rice yield. However, there is no significant negative effect of SRI on yield in most other countries (Fig. 1). Both Thailand and the Philippines had mean ln RRs < 0, although the means were not significantly different from 0 ($P = 0.083$, df = 4 and $P = 0.263$, df = 1 respectively; t-test) (Fig. 1). These results suggest that the introduction of SRI could increase or maintain rice yields over a broad range of geographic and climatic conditions.

Next we assessed if the regional variability found in the yield response to SRI could be explained by soil fertility. The soil type predicted by the ISRIC soil map agreed with soil information available in 22 of the reports. Of the 72 studies, only 15 provided soil texture information and seven provided soil pH. Soils with low pH ($\leqslant 5$) had been classified as low-fertility Acrisols and neutral pH ($\geqslant 6$) clay soils had been classified as Gleysols by the ISRIC soils map. The mean rice yields in SRI were 5.8, 7.0 and 7.7 t ha^{-1} in low-, moderate- and high-fertility soils, respectively. In the conventional systems, rice yields were on average 4.3, 6.1 and 7.4 t ha^{-1} in the low-, moderate- and high-fertility soils (Table 1). The rice yields therefore agreed with the soil fertility groupings, because lower yields were found in the low-fertility soils, higher yields were found in the moderate-fertility soils and the highest yields in the high-fertility soils.

The ln RRs were highly variable among soil types, likely due to the wide range of climatic conditions associated with studies included in the meta-analysis. When grouped by soil fertility, the mean ln RR of the high-fertility soils ($n = 19$) was -0.014 with the 95% confidence interval ranging from -0.07 to 0.10 (Fig. 2). In the moderate-fertility soils ($n = 17$), the mean ln RR was 0.18 and the 95% confidence intervals were -0.04 and 0.40 (Fig. 2). The mean ln RR of the low-fertility soils ($n = 36$) was 0.3061 and the 95% confidence intervals were 0.16 and 0.45. ANOVA showed that there was a significant effect of

soil fertility on ln RR ($P = 0.026$). Low- and high-fertility soils were significantly different (LSD, $P = 0.007$), whereas the moderate-fertility soils were not different from the low- (LSD, $P = 0.114$) and high- (LSD, $P = 0.330$) fertility soils. The mean ln RR of the low-fertility soils was significantly different from 0 (t-test, df = 35, $P < 0.0001$), whereas the mean ln RR of the medium- and high-fertility soils were not significantly different from 0 (t-test, df = 16, $P = 0.096$ and df = 18, $P = 0.745$, respectively). The data from peer-reviewed sources ($n = 8$) followed a similar trend as the complete data set. The average ln RR of the high-fertility soil group ($n = 4$) was 0.02, whereas the average ln RR of the low-fertility soil group ($n = 3$) was 0.29. These results show that SRI has a positive effect on rice yields in low-fertility soils, but no measurable effect on yields in moderate- to high-fertility soils. The adoption of SRI implies greater use of organic fertilizers than in conventional systems, and so SRI could be viewed as a low-input alternative with the potential to improve yields on low-fertility soils while maintaining yields and conserving resources on moderate- to high-fertility soils.

Global rice yields must increase by 50% in the next 20 years to meet the projected demand of the world's growing population[1]. Much of the increased demand will occur in areas with low-fertility soils, such as the highly weathered Acrisols and Ferralsols that are found in about two-thirds of the world's humid tropics[29]. By examining a larger number of field trials than considered previously[11], we demonstrate that SRI increases rice yields in regions other than Madagascar, namely in areas of Indonesia and India, where rice is the staple food. In most other countries, there is generally no yield loss in SRI compared to the conventional system. Furthermore, differences in soil fertility and potential for rice production can explain in part the regional variability in yield response to SRI. We found that SRI increases rice yields on low-fertility soils, and has no effect on yields in moderate- to high-fertility soils where yields are already high (about 7–10 t ha^{-1}). This agrees with the ideas outlined in a critical assessment of SRI by Dobermann[13]. In the context of augmenting food security while preserving natural resources, we suggest that SRI has the greatest potential to increase rice production on marginal soils, and thus could be an appropriate low-input technology for resource-poor farmers. Also, in areas where water is limited, the adoption of SRI may conserve water without sacrificing yields.

The mechanisms involved in the yield improvements with SRI on low-fertility soils remain poorly understood. Low-base cations are a key criterion in the classification of Acrisols and Ferralsols, and strongly weathered soils tend to be extremely low in available forms of phosphorus[30,31]. Here we posit four possible mechanisms whereby SRI modifies soil properties in a manner to increase rice yields on low-fertility soils: (1) aerobic conditions increase microbial activity, rates of organic fertilizer decomposition, organic phosphorus turnover and phosphorus availability in low-phosphorus soils[14,32–34]; (2) aerobic conditions favor root growth and increase nutrient acquisition by organically fertilized rice[3,5,13]; (3) wetting–drying cycles create aerobic conditions that reduce accumulation of toxic Fe^{2+} and Mn^{2+}[29,34]; and (4) low-potential soils may have high drainage or permeability making them unsuitable for flooding. Further research on the chemical and biological mechanisms involved in yield improvements with SRI on low-fertility soils is required in order to provide a scientific basis for agronomic recommendations and predictions of the long-term sustainability of this novel rice production system.

Conclusion

There is significant evidence that (1) SRI increases rice yields in regions other than Madagascar; and (2) SRI increases rice yields on low-fertility soils and has no effect on yields in moderate- to high-fertility soils. The results of this meta-data analysis should be considered as preliminary and replicated field trials with detailed soil fertility data are needed to improve our confidence in the yield differences between SRI and conventional rice production systems. The biological and chemical mechanisms that lead to increased rice yields on these low-fertility soils remain to be elucidated. Although the scientific debate over SRI continues, more than a million farmers around the world have now adopted the system[35]. We suggest that the minimum data set to be provided by future field studies comparing the SRI versus conventional system should include data on soil fertility class, texture, pH, macro-nutrient availability, fertilizer use and standard deviation of the mean yield value.

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Organic weed control in white lupin (*Lupinus albus* L.)

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Abstract

Legumes such as white lupin (*Lupinus albus* L.) provide a valuable nitrogen source in organic agriculture. With organic farming hectarage increasing and white lupin interest increasing in the southeastern USA due to newly released winter hardy cultivars, non-chemical weed control practices in lupin are needed. A two-year experiment was established at two locations in Alabama. Five weed control practices were evaluated: one pre-emergence (PRE)-applied herbicide (*S*-metolachlor), two mechanical (hand hoed) and two cultural (living mulch utilizing two black oat cultivars) weed control treatments. Fourteen weed species were encountered. *S*-metolachlor provided above 80% control of most weed species present in this experiment. The cultivation treatments and black oat companion crops also provided good weed control of many of the weeds encountered. Crop injury of all treatments was low on a 0 to 10 scale with 0 representing no injury: < 2.0, < 1.3 and < 1.2 by *S*-metolachlor, the cultivation treatments and the black oat companion crops, respectively. Grain yield of cultivars ABL 1082, AU Alpha and AU Homer were 1540, 1130, 850 kg ha^{-1}, respectively, when treated with the conventional treatment, *S*-metolachlor. Grain yield in the organic treatments was equivalent. The cultivation treatments and black oat companions were successful alternative weed control practices in white lupin production.

Key words: companion crop, cultivation, mechanical weed control

Introduction

Organic production is an increasing sector in US agriculture. To be certified as organic, a farm must follow the United States Department of Agriculture National Organic Program (NOP) guidelines. Conventional agriculture is dependent on synthetic nitrogen (N) fertilizers and herbicides for maximizing crop performance[1]. The NOP prohibits the use of synthetic herbicides and fertilizers[2]; therefore, alternative strategies for sufficient nutrient availability as well as for weed, insect and disease control are implemented in organic production.

Worldwide, 450 lupin species have been identified but only four species are used agronomically[3]. White lupin (*Lupinus albus* L.) was first introduced into the southeastern USA in the 1930s and the production eclipsed 1 million ha in the early 1950s. Hectarage subsequently declined due to loss of government support, damage to seed nurseries because of mid-autumn freezes in two consecutive years and the increased availability of inorganic fertilizers[4–6]. White lupin is of increasing interest in the southeastern USA because newly released cultivars exhibit vernalization requirements similar to wheat (*Triticum aestivum* L.). Winter-type cultivars offer an economic opportunity as an alternative legume cover crop, grain crop or forage. White lupin used in a winter cover crop rotation increased lint yield in cotton (*Gossypium hirsutum* L.) as compared to traditional rotations[6]. Furthermore, white lupin is attractive as mid-winter forage for ruminants due to a forage quality similar to that of alfalfa (*Medicago sativa* L.)[6].

Lupinus spp. are poor weed competitors during early establishment and canopy development is slow. Slow canopy development facilitates light penetration, weed seed germination and subsequent yield loss due to competition. Lupins reach maximum vegetative growth and competitiveness during flowering[7]. Weeds compete with lupin for water, nutrients and light; therefore, effective weed control, especially during early establishment, is necessary for the crop's success[7,8].

S-metolachlor, a chloroacetamide, is one of three active ingredients currently registered for use in US lupin production[9]. This pre-emergence (PRE)-applied herbicide provided good control of annual bluegrass (*Poa annua* L.), shepherd's purse (*Capsella bursa-pastoris* L.) and common

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chickweed (*Stellaria media* (L.) Vill.)[10]. *S*-metolachlor has been used for over a decade as a standard weed control program at Auburn University[11,12].

Mechanical and cultural weed control practices are important weed control alternatives in organic production. Hoeing is prohibitively expensive due to labor cost and hence is only used in high-value specialty crops or as supplement to other weed control practices. It is a successful weed control method for weed seedlings and annual/biennial weeds[13]. Lentil (*Lens culinaris* Med.) yield was found to be higher in hand-hoed plots than in plots in which herbicides such as linuron and metribuzin were applied[14].

Cover crops play a major role and are beneficial in any farming system such as conservation agriculture and organic farming. Some benefits include: reduction of soil erosion, reduction in pesticide use (herbicides, insecticides and fungicides), improved soil moisture, enhanced soil organic matter and breaking of pest cycles[15]. As a weed management tool, living cover crops are used to outcompete (smother) weeds, whereas desiccated cover crops are used as mulch, and both methods can release allelopathic chemicals[13]. Black oats (*Avena strigosa* Schreb.), a cool-season annual cereal, is a promising, relatively new cover crop in the southern USA and has been used successfully for many years as a cover crop for soybean [*Glycine max* (L.) Merr.] in Brazil[15]. Reasons for the success of this cover crop are its large biomass production and its exceptional allelopathic activity[16]. Even though black oat is successfully used as a weed management tool in soybean, cotton shows sensitivity to its allelopathic activity[17].

The specific objectives were to determine the effect of organic weed control practices such as cultivation and companion crops on weed control, injury to lupin, lupin density, lupin reproductive maturity and yield.

Materials and Methods

The experiment was conducted at two locations in October 2007 and 2008, respectively: the Alabama Agricultural Experiment Station E.V. Smith Research Center Field Crops Unit (FCU), near Shorter, AL (32.42N, 85.88W) on Compass loamy sand and at the E.V. Smith Research Center Plant Breeding Unit (PBU), near Tallassee, AL (32.49N, 85.89W) on Wickham sandy loam.

The experiment was a randomized complete block design (repeats = 4) with a 2 (year) × 2 (location) × 3 (lupin cultivar) × 5 (weed control) factorial treatment arrangement. Blocks were nested within year × location × cultivar combinations. The three lupin cultivars used were AU Homer (a high-alkaloid, indeterminate cover crop type), AU Alpha (a low-alkaloid, indeterminate forage type) and ABL 1082 (low-alkaloid, determinate grain-type experimental cultivar). The weed control factor had five levels: one pre-emergence (PRE)-applied herbicide (*S*-metolachlor), two mechanical (hand hoed) and two cultural (living mulch utilizing two black oat cultivars) weed control treatments. A non-treated control plot was also present.

Inoculated lupin were seeded in four rows with a John Deere® 1700 four row vacuum planter (Deere and Company, Moline, IL) with a row spacing of 90 cm at a depth of 1.25 cm in October 2007 and 2008. Smooth seed beds were prepared 2 weeks prior to planting in 2007. In 2008, raised beds were prepared with a KMC® four-row ripper/bedder (Kelley Manufacturing Company, Tifton, GA) due to concerns about waterlogging at both locations. The plot length was 6.0 or 7.5 m depending on location and year.

The conventional treatment *S*-metolachlor was applied at a rate of 1.12 kg a.i. ha^{-1} (one day after planting) with a compressed CO_2 backpack sprayer delivering 140 liters ha^{-1} at 147 kPa. The cultural control treatments, cv. SoilSaver and As 033 (a selection from PI 436103) black oat (*Avena strigosa* Schreb.) were hand sown 1 (2007) or 7 days (2008) after seeding of the lupin crop. The mechanical weed control treatments, between-row only cultivations and between and within row cultivation treatments were accomplished twice per year at 4 (2007) or 6 (2008) weeks after planting and 18 to 20 weeks, respectively.

Weed control ratings were recorded at both locations on a scale from 0% (no weed control) to 100% (complete weed control). The non-treated control was used to estimate the level of control in the treated plots. Two weed control ratings per treatment/plot were taken in each study year. The first rating was taken 6 weeks after planting and PRE application in both years. The second rating was taken 22 or 26 weeks after planting in 2007/2008 and 2008/2009, respectively.

Crop injury ratings were taken on a scale from 0 (no injury/alive) to 10 (complete injury/dead). In 2007/2008, crop injury ratings were taken 3 weeks after planting and PRE application and 15 weeks after planting. In 2008/2009, injury ratings were taken 4 weeks after planting and PRE application and 18 weeks after planting.

Stand counts were taken in the two center rows of each four-row plot along a 3-m pole. In 2007/2008, the first, second and third counts were taken 6, 11 and 16 weeks after planting, respectively. In 2008/2009, two counts were taken 4 and 8 weeks after planting. Due to frequent rains in winter 2008/2009, plots were inaccessible for a third stand count.

Maturity ratings on a scale from 0 (not in bloom) to 100% (full bloom) were taken to determine whether any treatments delayed maturity. The rating was taken at the end of March at both locations in both years.

To determine the plot yield as influenced by weed management practice, the two center rows of each plot were harvested with a plot combine. Plot samples were dried to constant weight, weighed and a sample taken to determine test weight and mean seed mass on a plot basis.

Mixed model procedures as implemented in SAS® PROC GLIMMIX (SAS Institute Inc., Cary, NC) were used to analyze weed control, crop injury, plant density, maturity and yield. Cultivar, weed control treatment and their interaction were treated as fixed effects. Location,

year and block (cultivar), their interaction with each other and fixed effects were considered to be random effects. All response variables, including weed control, were analyzed using the normal distribution function based on plots of standardized residuals. Occasionally, the GROUP option was employed to create variance groups for groups of treatments. Statistical significance was declared at Dunnett's $P < 0.1$.

Results

Weed control

During the experiment 14 weed species were encountered. None of the interactions and treatment main effects were significant for *Geranium carolinianum* L., *Trifolium incarnatum* L. and *Medicago lupulina* L. Cultivar by treatment interaction was non-significant, but treatment main effects were significant for all other weed species mentioned in Table 1. At the first rating 6 weeks after planting in 2007 and 2008, lesser swinecress [*Coronopus didymus* (L.) Sm] was controlled by *S*-metolachlor to 86%. Both organic living mulch black oat treatments provided much lower control ($\leqslant$28%). *S*-metolachlor provided 94% control of henbit (*Lamium amplexicaule* L.). With less than 25% control by both cultivation treatments and less than 62% control by both black oat cultivars, the organic treatments were inferior to *S*-metolachlor. The continuous germination of henbit[18] is likely the reason for poor control by organic treatments. Cutleaf-evening primrose (*Oenothera laciniata* Hill) was controlled to 99% by *S*-metolachlor and to 90% by both black oat cultivars. Both cultivation treatments provided much lower control ($\leqslant$25%). *S*-metolachlor controlled annual bluegrass (*Poa annua* L.) to 91%. With the exception of between–within row cultivation (73%), all of the remaining organic treatments provided lower control of this weed ($\leqslant$21%). Black oat cultivars SoilSaver (88%) and As 033 (82%) were as successful as *S*-metolachlor (82%) in controlling wild radish (*Raphanus raphanistrum* L.). With less than 35% control both cultivation treatments were inferior to *S*-metolachlor. Heartwing sorrel (*Rumex hastatulus* Baldw.) was controlled to 90% by *S*-metolachlor. With less than 60% control both black oat cultivars provided lower control than *S*-metolachlor. *S*-metolachlor provided 88% control of corn spurry (*Spergula arvensis* L.). The cultivation and companion crop treatments provided lower control than *S*-metolachlor. SoilSaver (90%) and As 033 (88%) were as successful as the conventional treatment (86%) in controlling winter vetch (*Vicia villosa* Roth).

At the second rating 22 weeks and 26 weeks after planting in 2007 and 2008, respectively, henbit, a winter annual weed species, was not present since its growing season ended earlier. Shepherd's purse [*Capsella bursa-pastoris* (L.) Medik.] was better controlled by the cultivation (>93%) and black oat companion crops (>90%) than by *S*-metolachlor. Control of lesser swinecress by *S*-metolachlor was reduced to 72%. Between–within row cultivation (94%) provided better control than *S*-metolachlor. Providing less than 51% control, the black oat companion crops were inferior to *S*-metolachlor. Cutleaf-evening primrose control by *S*-metolachlor (36%) was inferior at the second rating as compared to the first rating. With more than 70% control both cultivation treatments and both black oat companions provided better control than *S*-metolachlor. Germination of this weed species continued after the first rating. Annual bluegrass control by *S*-metolachlor was 93%. Between-row cultivation (60%) provided lower control than *S*-metolachlor. *S*-metolachlor provided 86% wild radish control. Between–within row cultivation (97%) provided superior control. Heartwing sorrel control by *S*-metolachlor was 77%. Both cultivation treatments provided better control (>90%) than *S*-metolachlor. Corn spurry control by *S*-metolachlor was 81%. Both cultivation treatments performed as successfully as the conventional treatment. SoilSaver and As 033 provided 58% and 66% control, respectively. *S*-metolachlor provided 79% winter vetch control.

Cultivar by treatment interaction was significant for annual ryegrass (*Lolium multiflorum* Lam.) (Table 2). Annual ryegrass was present only at the second rating. Mean control of annual ryegrass in cultivar ABL 1082 was 98%. Black oat cultivar As 033 provided excellent control (91%), but this was lower than control by *S*-metolachlor. AU Alpha weed control treatments provided equivalent weed control. Annual ryegrass was controlled 90% by *S*-metolachlor. With the exception of between-row cultivation (64%), none of the organic treatments provided lower control than *S*-metolachlor in AU Homer.

Similarly, cultivar by treatment interaction also was significant for yellow nutsedge (*Cyperus esculentus* L.). At the first rating, yellow nutsedge was controlled to 90% by *S*-metolachlor in ABL 1082. Between-row and between–within row cultivation both provided 12% control. Similar results were observed in cultivars AU Alpha and AU Homer. *S*-metolachlor provided 96% and 99% control of yellow nutsedge in AU Alpha and AU Homer, respectively. Both cultivation treatments (<37% control) were significantly inferior in both cultivars.

At the second rating, *S*-metolachlor provided $\geqslant$90% control of yellow nutsedge in all three cultivars. Between-row cultivation in ABL 1082 was the only treatment that provided lower control of yellow nutsedge than *S*-metolachlor. In AU Alpha the organic treatments controlled this weed to more than 77%. *S*-metolachlor and black oat companions each provided 99% control of yellow nutsedge at this rating.

Lupin injury

Treatment by cultivar interaction was non-significant at $P = 0.10$. Treatment main effects were significant. At the first rating, both cultivation and black oat treatments reduced crop injury compared to the *S*-metolachlor

Table 1. Weed control as affected by treatment 6 (2007 and 2008), 22 (2007) or 26 (2008) weeks after planting. Dunnett's test was performed to compare cultivation treatments and companion black oat treatments to a conventionally grown crop treated with *S*-metolachlor. Each species was analyzed separately, hence the different standard errors.

	***S*-metolachlor**		**Cultivation between rows**		**Cultivation between and within rows**		**Black oat 'SoilSaver'**		**Black oat 'As 033'**	
Weed species	**% Control**	**SE**	**% Control**	**Dunnett's *P*-value**	**% Control**	**Dunnett's *P*-value**	**% Control**	**Dunnett's *P*-value**	**% Control**	**Dunnett's *P*-value**
Rating 1										
Coronopus didymus (L.) Sm.	86	10.7	71	0.2146	83	0.9859	26	< 0.0001	28	0.0002
Lamium amplexicaule L.	94	11.4	46	< 0.0001	51	< 0.0001	62	< 0.0001	56	< 0.0001
Oenothera laciniata Hill	99	8.7	25	< 0.0001	21	< 0.0001	90	0.6814	90	0.5781
Poa annua L.	91	9.4	67	0.0521	73	0.4028	59	0.0490	42	0.0019
Raphanus raphanistrum L.	82	12.6	34	0.0094	17	< 0.0001	88	0.9252	82	1.0000
Rumex hastatulus Baldw.	90	9.7	81	0.0310	87	0.8187	59	0.0007	53	< 0.0001
Spergula arvensis L.	88	8.5	43	< 0.0001	49	< 0.0001	59	0.0003	56	0.0001
Vicia villosa Roth	86	10.3	25	< 0.0001	21	< 0.0001	90	0.9781	88	0.9958
Rating 2										
Capsella bursa-pastoris (L.) Medik.	82	7.2	93	0.0098	94	0.0066	90	0.1011	93	0.0131
Coronopus didymus (L.) Sm.	72	11.1	74	0.9949	94	0.0548	51	0.0691	36	0.0273
Oenothera laciniata Hill	36	5.8	71	< 0.0001	85	< 0.0001	74	< 0.0001	75	< 0.0001
Poa annua L.	93	3.9	60	< 0.0001	84	0.1954	86	0.3631	86	0.3631
Raphanus raphanistrum L.	83	6.1	90	0.7898	97	0.0474	85	0.9950	81	0.9944
Rumex hastatulus Baldw.	77	6.1	94	0.0054	98	0.0007	77	1.0000	74	0.9806
Spergula arvensis L.	81	13.1	81	1.0000	81	1.0000	58	< 0.0001	66	0.0329
Vicia villosa Roth	79	5.8	91	0.1299	91	0.1014	75	0.9229	76	0.9881

Table 2. Control of annual ryegrass (*Lolium multiflorum* Lam.) and yellow nutsedge (*Cyperus esculentus* L.) in *L. albus* L. cultivars as affected by treatment 6 (2007 and 2008), 22 (2007) or 26 (2008) weeks after planting. Dunnett's test was performed to compare cultivation treatments and companion black oat treatments to a conventionally grown crop treated with *S*-metolachlor. The group option was employed to account for heterogeneous variances among treatments, hence the varying standard errors.

	Lolium multiflorum Lam.			*Cyperus esculentus* L.					
	Rating 2			Rating 1			Rating 2		
Cultivar treatment	% control	SE	Dunnett's *P*-value	% control	SE	Dunnett's *P*-value	% control	SE	Dunnett's *P*-value
ABL 1082									
S-metolachlor	98	5.6		90	9.5		94	13.7	
Cultivation between rows	97	8.1	1.0000	12	9.5	< 0.0001	35	13.7	0.0158
Cultivation between and within rows	99	5.5	0.9944	12	9.5	< 0.0001	45	13.7	0.0519
Black oat 'SoilSaver'	99	5.8	0.9996	91	9.5	1.0000	99	13.7	0.9973
Black oat 'As 033'	91	5.1	0.0765	89	9.5	1.0000	99	13.7	0.9973
AU Alpha									
S-metolachlor	94	5.6		96	11.0		92	6.6	
Cultivation between rows	96	8.5	0.9957	37	11.0	0.0002	77	6.6	0.2783
Cultivation between and within rows	95	5.6	0.9973	25	11.0	< 0.0001	94	6.6	0.9969
Black oat 'SoilSaver'	94	5.9	1.0000	98	11.0	0.9998	98	6.6	0.8980
Black oat 'As 033'	92	5.1	0.8737	97	11.0	1.0000	99	6.6	0.8398
AU Homer									
S-metolachlor	90	5.8		99	11.0		99	6.6	
Cultivation between rows	64	8.9	0.0090	24	11.0	< 0.0001	99	6.6	1.0000
Cultivation between and within rows	87	5.7	0.9286	23	11.0	< 0.0001	99	6.6	1.0000
Black oat 'SoilSaver'	85	6.1	0.6616	99	11.0	1.0000	99	6.6	1.0000
Black oat 'As 033'	94	5.3	0.5368	96	11.7	0.9995	99	7.7	1.0000

treatment (0.97). Crop injury increased over time. At the second rating only between-row cultivation (1.04) and black oat cultivar As 033 (0.87) caused lower injury than the *S*-metolachlor treatment (1.61). Overall, crop injury was negligible and well below reported thresholds.

Lupin density

The interactions and treatment main effects were non-significant ($P = 0.10$). Plant density of the cultivars decreased over time from rating 1 to 3. ABL 1082 plant density was 9.8, 9.1 and 8.8 plants m^{-2} for ratings 1, 2 and 3, respectively. Density of AU Alpha was 10.6, 9.5 and 7.6 plants m^{-2}. AU Homer was 10.6, 9.6 and 9.3 plants m^{-2}. The slight decrease in plant density may be related to plant death over time due to insects, deer browsing and disease.

Lupin maturity

The interactions and treatment main effects were non-significant ($P = 0.10$). At the March rating it was observed that ABL 1082 is slightly later maturing because 82% of the plants were in full bloom as compared to 89% for AU Alpha and AU Homer. This is consistent with the breeding history of these cultivars (van Santen, 2006, unpublished results).

Lupin yield

The treatment by cultivar interaction was significant for test weight and yield, but not for seed mass. Treatment main effects were significant for test weight, seed mass and yield. Plants of ABL 1082 treated with *S*-metolachlor had a test weight of 79.6 kg 100 liter^{-1}. Only black oat As 033 (78.6 kg 100 liter^{-1}) resulted in a lower test weight (Table 3). Neither cultivation nor black oat cultivar treatments altered the mean seed mass of ABL 1082 as compared to *S*-metolachlor (210 mg seed^{-1}). ABL 1082 plants treated with the conventional treatment had a grain yield of 1540 kg ha^{-1}. With the exception of between-row cultivation (1904 kg ha^{-1}) none of the organic treatments significantly increased the yield of ABL 1082.

The test weight of AU Alpha treated with *S*-metolachlor was 77.5 kg 100 liter^{-1} (Table 3). Both black oat cultivars reduced the test weight ($\leqslant$76.3 kg 100 liter^{-1}) compared to *S*-metolachlor. None of the organic treatments either increased or decreased mean seed mass in comparison to *S*-metolachlor (227 mg seed^{-1}). AU Alpha treated with *S*-metolachlor yielded 1126 kg ha^{-1}. Neither cultivation

Table 3. Test weight (kg 100 liter^{-1}), seed mass (mg seed^{-1}) and yield (kg ha^{-1}) of *L. albus* L. as affected by treatment.

Treatment		Test weight		Seed mass		Grain yield	
Name	Class	Mean (kg 100 liter^{-1})	Dunnett's *P*-value	Mean (mg seed^{-1})	Dunnett's *P*-value	Mean (kg ha^{-1})	Dunnett's *P*-value
ABL 1082							
S-metolachlor	Conventional	79.6	-	210		1543	
Cultivation between rows	Organic	80.1	0.800	217	0.445	1904	0.013
Cultivation between and within rows	Organic	80.2	0.610	214	0.886	1678	0.690
Black oat 'SoilSaver'	Organic	79.5	0.996	202	0.482	1424	0.779
Black oat 'As 033'	Organic	78.6	0.085	213	0.959	1290	0.138
Non-treated	Control	80.1	0.715	215	0.783	1705	0.524
AU Alpha							
S-metolachlor	Conventional	77.5		227		1126	
Cultivation between rows	Organic	77.7	0.985	231	0.895	1214	0.919
Cultivation between and within rows	Organic	77.5	1.000	233	0.722	1151	1.000
Black oat 'SoilSaver'	Organic	76.2	0.145	230	0.954	939	0.390
Black oat 'As 033'	Organic	76.3	0.068	233	0.744	909	0.296
Non-treated	Control	77.6	0.993	233	0.674	1330	0.305
AU Homer							
S-metolachlor	Conventional	76.4		222		849	
Cultivation between rows	Organic	76.5	0.997	231	0.278	1020	0.473
Cultivation between and within rows	Organic	76.3	0.999	236	0.046	1018	0.482
Black oat 'SoilSaver'	Organic	76.3	0.999	235	0.070	934	0.931
Black oat 'As 033'	Organic	76.9	0.672	232	0.246	1067	0.247
Non-treated	Control	76.3	1.000	236	0.034	887	0.998
SE		0.48		11.6		232.4	

nor black oat cultivars influenced the test weight of AU Homer as compared to *S*-metolachlor (76.4 kg 100 liter^{-1}) (Table 3). Plants treated with *S*-metolachlor resulted in a seed mass of 222 mg seed^{-1}. Seed mass was higher in non-treated plants (236 mg seed^{-1}), as compared to the seed mass of plants in which between–within row cultivation (236 mg seed^{-1}) and black oat cultivar SoilSaver (235 mg seed^{-1}) were used. None of the organic treatments reduced or increased the grain yield of AU Homer as compared to *S*-metolachlor (849 kg ha^{-1}).

Discussion and Conclusion

Our results show that between and within row cultivation successfully reduced most weed species that were present in our experiment to more than 80%, including Shepherd's purse, annual ryegrass, winter vetch and heartwing sorrel. The cultivation treatments, between row and between–within row (hoeing) yielded as high or higher than the non-treated control and higher than *S*-metolachlor. This coincides with observations made in lentil[13], in which hand-hoed plots yielded higher than chemical weed control. Test weight and seed mass were not reduced or increased by cultivation treatments. Yield potential may be higher in these treatments since crop injury was lower compared to the *S*-metolachlor treatment.

The two black oat cultivars provided very good control of annual ryegrass, shepherd's purse and yellow nutsedge (>90%), but were not successful in the control of other weed species, especially corn spurry (*Spergula arvensis* L.). Black oat can be grown as a companion crop in lupin, growing in the same field at the same time. In conventional farming systems, the black oat companion may be terminated by a selective grass herbicide (i.e. aryloxyphenoxypropionates and/or cyclohexanediones) prior to lupin harvest. Black oat, especially SoilSaver, out-competes weeds by shading due to its large biomass production[15]. Black oat also produces allelopathic compounds that inhibit weed growth[15]. This is particularly important since lupins have a slowly developing canopy during their early establishment which inhibits their ability to shade weeds themselves. Neither of the black oat cultivars resulted in crop injury. This may indicate that white lupin, unlike cotton[16], is not sensitive to the allelopathic activity of black oat. Neither of the black oat companions affected the yield of any lupin cultivar.

Stand count reductions appear more closely related to yield loss than other parameters, including crop injury[19]. Based on previous research it was found that crop injury greater than 3 is unacceptable in white lupin[20].

We conclude that organic production of white lupin in the southeastern USA is possible. The cultivation

treatments and companion crops used in this experiment provide satisfactory to excellent weed control without causing unacceptable crop injury. Plants treated with these organic methods yielded as high or higher than the chemical control, which makes the production of organic seed feasible.

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Analysis of fertilizer subsidy programs and ecosystem services in Malawi

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Abstract

This paper evaluates the delivery of ecosystem services under different regimes of agricultural input subsidy in post-independent Malawi using (1) the protocol of the Millennium Ecosystem Service to characterize the services; and (2) the panarchy framework to describe the relationships among the political regimes, economic growth [gross domestic product (GDP)] and food security. Ecosystem services are the benefits that humans obtain from ecosystems that support, directly or indirectly, human survival and quality of life. Panarchy is a nested set of adaptive cycles that provides a tool to explore the conductivity of ecological and social-cultural systems. The Malawian temporal political landscape has experienced several reorganizations since independence, in which the governments of Malawi have initiated socio-economic growth of the economy through implementation of different farmer input subsidy programs with variable success. The most recent agricultural subsidy program (2005–2009) appears to have shown an improvement in food security for the people of Malawi. However, this may be at the expense of an increased rate of decline in other ecosystem services, especially arable land resources and forestry. If agricultural subsidies continue to be implemented without a holistic understanding of all ecosystem services delivered to the whole country, then the system will be unsustainable. We recommend the ecosystem service approach and the panarchy framework as potentially useful tools for policy makers.

Key words: human well-being, agricultural economic growth, socio-ecological systems, panarchy

Introduction

Developing robust and effective evidence-based policies for economic growth and food security should be the aim of all governments. However, data covering all aspects involved in policy initiatives and their implementation instruments are seldom available to policy makers. Over the past decade, the concept of using ecosystem services to measure the effectiveness of government socio-economic policies has attracted a lot of attention. Ecosystem services encompass both the economic[1] and non-economic benefits which ecosystems deliver[2]. They are often defined as the benefits that humans obtain from ecosystems that support, directly or indirectly, human survival and quality of life[3–6]. Some ecosystem system service benefits, such as crops, fish and freshwater (provisioning services), are tangible. Others such as pollination, erosion regulation, climate regulation (regulating services) and aesthetic and spiritual fulfillment (cultural services) are less tangible. The concept of ecosystem services has been adopted by many countries, but it is particularly important in developing countries which are experiencing accelerated degradation of ecosystem services[7].

In developing countries such as Malawi a dilemma facing policy makers and development workers is the need to strike a balance between improving the lives of the rural poor, without causing undue degradation of the ecosystem on which these people depend for their livelihoods. This is not an easy task, as demonstrated by the introduction of agricultural input subsidies in post-colonial Africa. An evaluation of policies in Africa[8] concluded that the main donors believed that agricultural input subsidies in the 1980s and 1990s had been ineffective and inefficient policy instruments. They argued that national agricultural input subsidies in Africa had contributed to government overspending and added to fiscal and macroeconomic problems. Agricultural input subsidies have also been criticized by environmentalists and others for causing environmental disasters in countries where subsidies were effective for agricultural production. The environmental impacts of the use of chemical inputs implicated in the Green Revolution (GR) technology package have caused serious soil and water degradation[9].

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Table 1. Time line of factors associated with Malawian agriculture since the 1960s.

Period	Political regime	Socio-economic agricultural environment	Agricultural practices characterizing the phase	Extreme weather events
Before 1964	British colonial rule	No direct government financial support for smallholder agriculture	Shifting cultivation/ subsistent farming	Little documented
1964–1979	Post colonial/ independence,	Smallholder farm input credit support started	Reduced shifting cultivation, increased	
1980–1993	one-party rule	Start of economic SAP supported by the WB (International Money Fund: IMF) and other donors which did not favor input subsidies	use of inorganic soil fertility inputs	1991–1992 Drought resulted in poor harvest and national hunger
1994–1997	Democratic elections	SAP philosophy stronger against direct financial agricultural support		1995–1996 Poor harvest
1998–2003		National government initiates support via 'Starter pack' program for 2 years		2001–2002 Drought and floods resulted in poor harvest and national hunger
2004–present	Democratic elections Change of Leadership to President	Despite IMF disapproval, national government initiates increased direct financial support via the Targeted Inputs Scheme (TIPs) in the 2004/2005 and FISP in 2005/2006	Shifting cultivation almost completely abandoned. Fertilizer subsidies re-established	2004–2005 Severe drought and floods resulted in poor harvest and national hunger

FISP, Farm Input Subsidies Program; SAP, Structural Adjustment Programs; WB, World Bank.

While we understand that subsidies, controversial as they may be, have been part of the development agenda in Malawi since the 1960s, there is a lack of information on how they influence provision of ecosystem services in the wider context. In this paper, we use the concept of ecosystem services to assess the link between ecosystems and human well-being in the Malawi context. As a case study, the influence of the Malawian government agricultural policy of fertilizer subsidy is examined and its ability to meet the ecosystem services' needs of the people is evaluated using the Millennium Ecosystem Service approach[10,11]. Further, the effect of the subsidy programs on aspects of the wider environment and on the arable and forest land availability is investigated. Finally, the dynamics and the social-ecological temporal changes in the political, food security and economic status of the country under the different subsidy implementation phases are considered using the panarchy framework[12].

Data were obtained from the World resources Institute and FAOSTAT databases. Cereal requirements of the population, which mostly comprise maize, were computed from a calculated per capita cereal requirement of approximately 153 kg per annum[13]. Data are presented on overall provisioning (food) services, gross domestic product (GDP) in US$ per capita and the total production per capita index.

Malawi Political Landscape and Food Production

Malawi is a small country in southern Africa with a population of approximately 13 million people. Overall, Malawi has one of the highest population densities in the world at 129 persons/km^2. More than 40% of smallholders in Malawi are reported to cultivate less than 0.5 ha, with an average farm size of 0.28 ha.[14] Areas with the smallest average farm size have the highest poverty, and poor households are much more likely to have farm sizes of less than 1 ha than households with income above the 40th percentile[14].

The country has experienced significant changes in the political regimes since the 1960s. It was under British colonial rule from 1929 but became independent in 1964 and was governed as a one-party-state until 1994 when the first democratic government came to power.

Malawi's economy is based on agriculture, which currently accounts for about 35% of Gross National Product and more than 80% of the country's export earnings[15]. At least 80% of agricultural produce comes from smallholder farmers on customary land. The rest is produced by commercial farmers on estates. The overall aim of successive Malawian governments has been to meet the subsistent food needs of the people and thereafter export agricultural products for cash generation. In order to achieve this objective, farmers in Malawi have been supported with various forms of input credit schemes to boost agricultural production since 1964 (Table 1).

State Subsidies, Agricultural Productivity and Economic Growth

Malawi's agriculture has been characterized by small-scale farm-producers who have received varying degrees of input

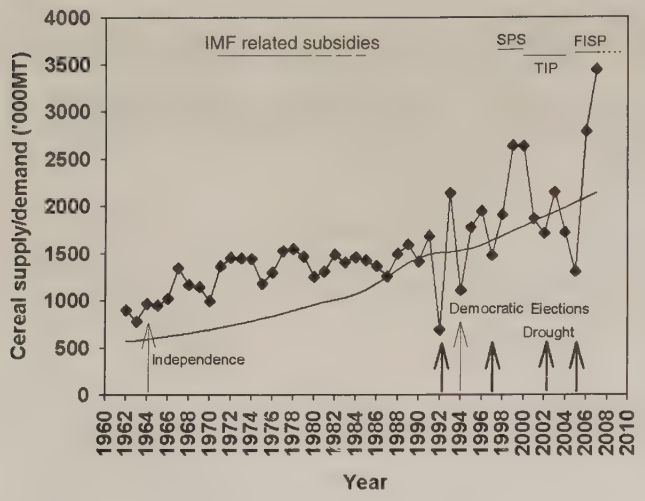

Figure 1. Cereals produced (square symbol) and cereal requirements (solid line) for Malawi ('000 metric tons). Compiled from World Resources Institute (WRI) and Food and Agriculture Organization (FAO) data sources. Cereals include wheat, barley, maize, rye, oats, millet, sorghum, rice and buckwheat, for a complete definition please refer to the web page maintained by FAOSTAT at http://www.fao.org/waicent/faostat/agricult/prod-e.htm. Cereal requirements computed based on cereal production, population figures and the 2007 requirement of approximately 2 million tons[13].

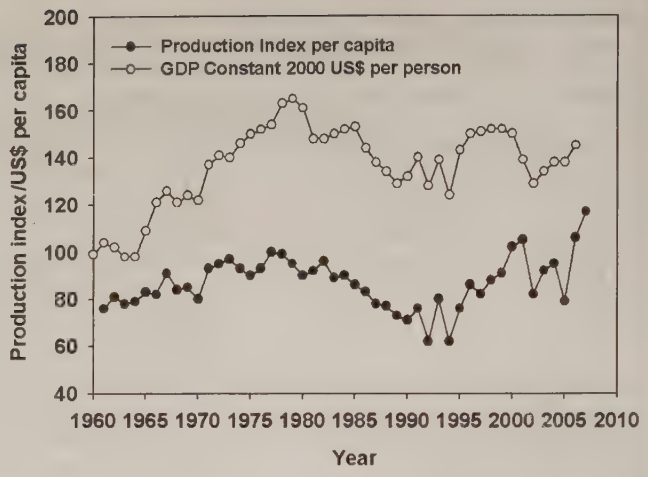

Figure 2. (○) GDP per capita, constant US$. Source: Compiled from World Resources Institute (WRI). GDP: a measure of the size of economies, reported here in million constant 2000 US$. GDP is the total market value of all final goods and services produced in a country in a given year, equal to total consumer, investment and government spending. In this case, it is shown in constant US$ to allow for the comparison of GDP across years without interference from the effects of inflation on prices. (●) The total production per capita index volume of the country's agricultural sector per person relative to the base period 1999–2001. The agricultural production index of WRI includes all crop and livestock products originating in the country. Intermediate agricultural products, including fodder crops, are not counted.

subsidy support over time. As stated above, conventional wisdom among policy analysts in the 1980s and 1990s was that subsidies had been ineffective and were inefficient policy instruments in Africa[8]. It was commonly believed that they contributed to government over-spending as well as fiscal and macro-economic problems[16]. This thinking brought about structural adjustment programs (SAPs) instituted by the World Bank (WB) and the International Monetary Fund (IMF)[17]. In response to these international pressures, Malawi has undertaken SAPs supported by the WB, the IMF and other donors since 1981[15]. Owing to the erratic weather patterns and droughts in the 1992–1993, 1994–1995 growing seasons with subsequent poor crop harvests that seriously affected food production and persistent hunger, the Malawi government reintroduced government-funded subsidy programs on several occasions during the past two decades (Fig. 1). The Starter Pack Scheme (SPS) for example, ran basically from 1997 to 1999, and essentially distributed free packs of fertilizer and matching quantities of maize seed for 0.1 ha of land to farmers throughout the country. A similar scheme, the Targeted Inputs Scheme (TIPs) lasted from 2000 to 2004. In defiance of the international community and IMF disapproval of input subsidies, the current government reintroduced a large-scale input subsidy in the 2005/06 season referred to here as the Farm Input Subsidies Program (FISP) with the stated objectives of promoting access to and use of fertilizers in both maize and tobacco production. This was in response to another serious food shortage in 2004/2005 emanating from a serious drought that year (Fig. 1).

Input Subsidies and Cereal Production

Overall, it has been estimated that nationally maize production increased by 46% from 1.5 million tons in 1997/98 to around 2.2 million tons in 1999/2000. In the 2005–2006 season, which had good rains, the total maize production was more than double that of the 2004–2005 harvest, producing a surplus of 510,000 t above the national maize requirement[13]. Incremental maize production attributed to the fertilizer subsidy was estimated at 300,000 to 400,000 t. The 2006–2007 harvest was estimated at 3.44 million t, an all-time national record for Malawi, generating a surplus of about 1.34 million t of maize grain above national requirements[13].

Cereal production and estimated cereal demand by the population of Malawi is shown in Figure 1 (smooth curve for cereal demand). National cereal demand shows that generally Malawi had adequate supplies to meet the subsistent needs of the people from independence to 1986 (Fig. 1) but food deficits in the 1991–1992, 1993–1994, 1996–1997, 2000–2001, 2001–2002, 2003–2004 and 2004–2005 harvest years. These data signify how food insecure the country has been in the past 20 years.

Agriculture and the Economy

The importance of agricultural produce to the economy of Malawi can be illustrated using two common indices reported by the World Resource Institute: (1) GDP per capita and (2) the total production per capita index (Fig. 2).

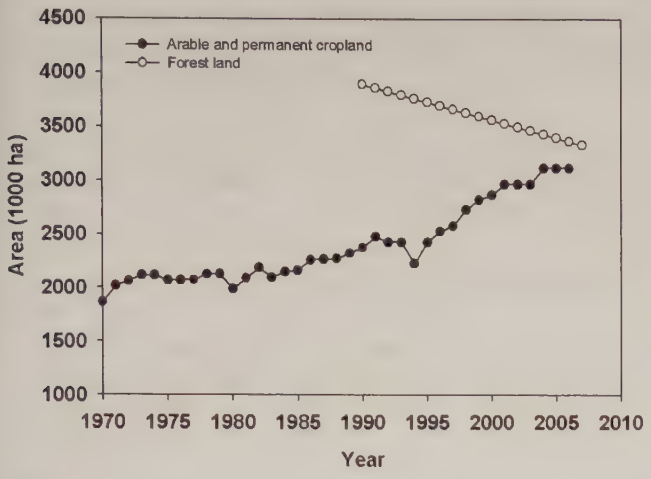

Figure 3. FAOSTAT estimate of the forest and cropland in Malawi (cropland estimated manually, forest area estimated manually 2007 and a standard reduction factor applied in other years—see text for full explanation).

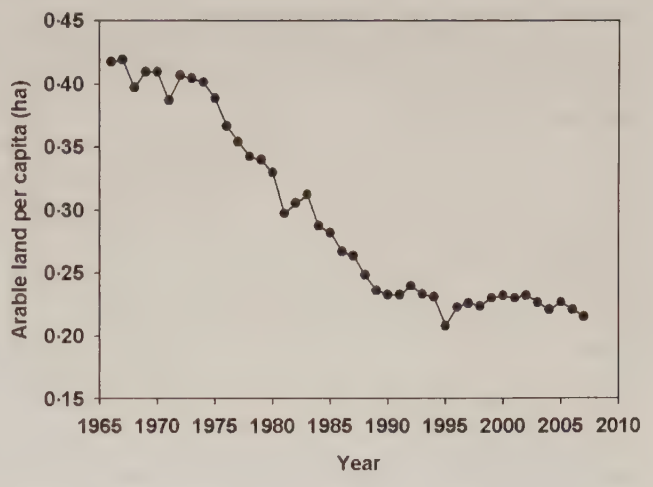

Figure 4. Arable land (ha) per capita for Malawi.

The data reveal that following independence in 1964 until around 1979 the country enjoyed some economic growth. This high economic growth rate was driven primarily by tobacco and tea exports[18]. The GDP growth for the first 15 years of independence averaged 6% every year, but both social and natural forces in the country (political power struggle and climatic extremes) resulted in a more erratic pattern of annual GDP thereafter[18]. A critical policy reform on population and agriculture needs to be put in place in order to balance the land–population equation and to sustain the benefits from policies such as the FISP being implemented at present.

Land and Forestry Ecosystems

We evaluated the balance between forestry and arable land resources in the country (Fig. 3). The FAOSTAT database reports a steady decline in arable land per capita for Malawi since independence (Fig. 4). It is not possible from the data available to separate the two primary drivers of forest degradation, population increase and conversion of land for agriculture. However, population increase may be the more important driver as research has shown that households which were receiving a free packet of hybrid maize seed and chemical fertilizer had lower levels of commercial forest extraction than non-recipient households[17]. In addition, no measurable effect of starter pack receipt was found on forest clearing decisions. These results therefore suggested that the program raised agricultural output without encouraging agricultural land expansion. These findings indicated potential modest improvement in forest condition due to the SPS[17]. However, the starter pack was only exercised from 1997 to 1999 and is therefore deemed too short a period to make a full judgment of its effect on land-use changes. Long-term effects of such a practice may be different and are worth exploring.

Fertilizer Subsidy and Delivery of Ecosystem Services

There is limited data on the influence of the fertilizer subsidy policies on ecosystem services within the wider society of Malawi other than food production. Data on ecosystem services such as water quality, fuel wood supply, cultural diversity, etc. are often not collected or, if collected nationally, are not accessible to national or international research communities. Similar observations on data availability were made on the global status of ecosystem services during the Millennium Ecosystem Assessment[11]. In this paper, we have estimated the expected change and direction of change associated with fertilizer subsidies on a suite of ecosystem services (Table 2). The direction of change is derived from personal observations by the main author and from suggestions provided by a wide range of scientific, grey and web-based publications, including the Millennium Ecosystem Assessment[10,11]. In total, the influence of agricultural input subsidies was assessed for 29 ecosystem goods and services (Table 2). Although it is widely recognized, as detailed above, that the current fertilizer subsidy has had a positive influence on food production, its effect would be expected to have been negative for fuel wood production as people may become more prosperous and use more fuel, leading to the decline in forest. The Starter Pack Policy did not lead to increase in land clearance for cultivation in the southern region of Malawi[17]. However, evidence from land-use data (Fig. 3) suggests that there is potentially a negative long-term effect on the regulating services primarily through the actions of woodland clearance and increased soil disturbance. It is not clear whether fertilizer subsidy policies are directly increasing forest clearance rates or whether the driver is simply population pressure. It must be noted that the rate of forest clearance is probably subject to a larger uncertainty as it is modeled data. This highlights the need for governments to conduct studies for determining the effect that agricultural input subsidies have had on the forests and other ecosystem services.

Table 2. Predicted effect of subsidies on Malawi ecosystem services based on Millennium Ecosystem Assessment definitions[11].

Ecosystem service	Effect of agricultural input subsidies	
Provisioning services		
Food	↑	Increased substantially
Fiber	↑	Potentially increase cotton production following diversion of fertilizer input
Genetic resources	↔	Minimal effect expected at present but lack of data
Biochemicals and pharmaceuticals	↔	
Ornamental resources	↔	
Fuel	↓	Potentially reduced as woodland converted to arable, currently only a problem close to large cities
Fresh water	↓	Potentially negative if excess fertilizer leaked into the water table; currently no data related to Malawi but evidence from other countries suggests this may be a problem in the future
Regulating services		
Regulation of human diseases	↔	Little impact expected at present but lack of data
Air quality regulation	↓	Potentially negative as increase crop production usually leads to increased pesticide use
Climate regulation	↓	Potentially reduced due to increased emissions of soil sourced nitrous oxide emissions, a potent greenhouse gas, if subsidy continues in the long term
Water regulation	↓	Potentially negative as more water may be needed for irrigation; minimal effect noted at present but lack of data
Erosion regulation	↓	Potentially reduced through conversion of woodland to arable land and ploughing
Water purification and waste treatment	↓	Potentially reduced as minimal ground vegetation following harvest of arable crops
Biological control	↓	Potentially reduced due to woodland clearing—a source of biological control agents
Pollination	↓	Potentially reduced due to woodland clearance, although may be increased if arable crop a significant source of pollinator food
Storm protection/natural hazard regulation	↓	Potentially reduced due to land clearing for cultivation
Cultural services		
Knowledge systems	↑	Potential increase due to food security
Educational values	↑	Potential increase due to food security
Sense of place	↑	Potentially increased due to improved food security
Cultural diversity	↔	Minimal effect expected at present but lack of data
Spiritual and religious values	↔	Minimal effect as religious and spiritual sites are protected by local custom
Cultural heritage	↔	Minimal effect as long as small-scale agriculture is practiced
Inspiration	↔	
Aesthetic values	↔	
Recreation and ecotourism	↔	Potentially reduced because landscape less diverse but could argue potentially increased as people have more leisure time
Social relations	↓	Potentially reduced due to reduced rate of peace work
Supporting services		
Nutrient cycling	↑	Potentially increased as the crop residue left following harvest encouraged microbial activity unless crop residue burnt
Soil formation	↓	Potentially reduced as associated effect of erosion
Photosynthesis	↓	Reduced net primary productivity due to woodland conversion to arable land.
Primary production	↓	Potentially reduced unless in agroforestry system

We also anticipate that the potential of nitrogen leakage from agricultural fields into water courses would increase in the long term and it is possible that the provision of fresh water may also be compromised (Table 2) as has been reported by the Millennium Assessment in those areas with increased use of inorganic fertilizers[11]. Again, this is difficult to ascertain in the absence of reliable data.

Our observations suggest that as food security increases, the well-being of the population, level of education, social relations and sense of place delivered by an ecosystem would increase. We also believe that the increased level of fertilizer available to farmers through input subsidies has resulted in a greater number of the poorest farmers being able to support their families without the need to work on more wealthy farms. This may effectively reduce the employment of casual workers which may lead to reduced social relations in the community. The hypothesis here is that subsidies lead to improved food sufficiency for small farmers as evidenced by the data presented above and reduces their dependency as casual farm laborers on other

commercial and large farmers. This would then reduce social interactions among the communities. Although in some places, e.g., large estates, the landscape has become more homogeneous, with cheap fertilizer, this may also bring about a negative effect on the recreation and ecotourism offered by these ecosystems due to declining forest resources. This was considered a small influence in Malawi to date as ecotourism is currently not fully developed as an ecosystem service and a direct link between subsidy and forest clearance has not been substantiated.

The supporting services are by definition a composite of many complex interactions and it is therefore more difficult to predict the influence of fertilizer policy changes on them. Nonetheless, it is estimated that more intensive agriculture will reduce soil formation, photosynthesis and water cycle especially when inorganic fertilizers from subsidies are used exclusive of organic amendments such as applying green manures from agroforestry. Our assessment suggests that overall around 50% of the ecosystem services considered in Table 2 may be negatively affected by agricultural input subsidies if Malawi embraces the use of inorganic fertilizer as seen in other countries around the world[11]. Most concern is centered on the regulating and supporting services with 88 and 75% of services, respectively, listed in Table 2 estimated to be potentially negatively influenced by agricultural input subsidies.

It is clear from this analysis that there are insufficient data to accurately determine the effect of agricultural input subsidies on a wide array of ecosystem services. This analysis is important to highlight the area on which the government should concentrate its efforts. As many of the services are directly related to land-use change, this would appear to be the most important area for government scrutiny.

A Social-ecological Systems' Perspective of Malawi's Agriculture and Input Subsidies

In order to obtain a clearer understanding of the interactions of the social-ecological system of Malawi and the influence of agricultural input subsidies we utilized the panarchy model[12]. Panarchy had its origins in Holling's meticulous observation of the ecology of forests. Holling noticed that healthy forests all have an adaptive cycle of growth, collapse, regeneration and growth again and that this cyclic phenomenon is applicable to social and economic facets of the world. According to the web-based encyclopedia Wikipedia (http://en.wikipedia.org/wiki/Panarchy; accessed 18 June 2010), the term panarchy has in fact been coined separately by scholars in international relations to describe the notion of global governance and by system theorists to describe non-hierarchical organizing theories. A panarchy here is a nested set of adaptive cycles operating at discrete scales[12]. The adaptive cycle embraces two opposites: growth and stability on the one hand, change and variety on the other. The adaptive cycle consists of four phases: (1) 'exploitation' (r); (2) 'conservation' (K); (3) 'release' (Ω) or 'creative destruction' and (4) 'reorganization' (α). The shape looks like a mobius strip, a distorted figure eight or infinity symbol floating in three-dimensional space with conductivity, potential and resilience as the three axes[12].

Discontinuities are thresholds between the dynamic levels, i.e., adaptive cycles, of a panarchy[12]. Discontinuities are manifest in key cross-scale variables. Three distinct kinds of change are reported within panarchies: (1) incremental change in the r and K phases, which are smooth and fairly predictable; (2) abrupt change in the transitions from K through Ω and α; and (3) transformational learning, meaning change involving several panarchical levels and interaction between different sets of labile variables[19].

In order to get a clearer understanding of the impact of policy decisions on the food security of the Malawi nation, we use the panarchy model to examine the social ecological changes that have occurred in the course of the agricultural policies described in this paper. Figure 5 has been constructed to show a time course of Malawi agriculture in terms of its political landscape, food security status and GDP. The time course is based on periods of change in either political regime and/or incidences of extreme weather events which are considered to drive the adaptive cycles under discussion. These are tipping points in the panarchy. We interpret the adaptive scales for the political regime, GDP and food security using knowledge from the literature and data presented in Figures 1 and 2.

Panarchy Adaptive Cycles of Malawi Policies and Agriculture

The newly won independence of 1964 meant that the country was politically in its re-organization (α) phase of the panarchy following the collapse of the colonial rule which had in panarchy terms undergone a 'creative destruction' (Ω), i.e., tipping point in the civil governance of the country. Being an agro-based economy, the post-independence years (1964–1969) saw Malawi investing heavily in agriculture, which resulted in a growth of the food sector and the economy (GDP). Data on GDP (Fig. 2) and overall cereal production (Fig. 1) show a relatively steady period of growth, while the nation reorganized politically and experienced growth of the economy and increased food security (panachy phase r). This lasted between 1970 and 1980, when Malawi also enjoyed a period of fairly stable government. The withdrawal of agricultural input subsidies as a result of the SAPs weakened farmers' productivity towards the end of the 1980s, putting the country on the verge of food security collapse (Fig. 1, 1987 food deficit). This was associated with an obvious decline of the GDP from around 1982 (Fig. 2). Malawi also suffered a severe drought in 1992–1993 rainy seasons. With the phasing out of the SAPs

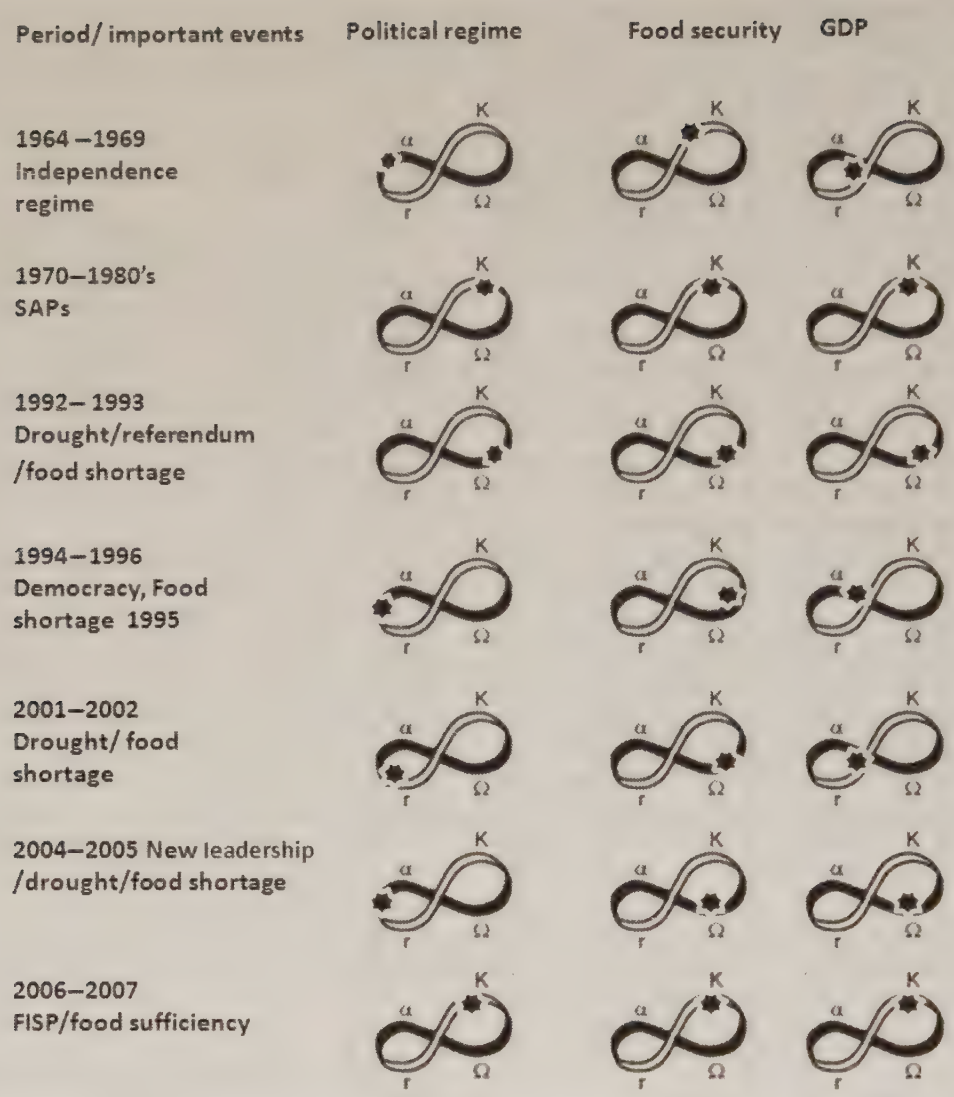

Figure 5. Series of adaptive cycles of the (i) politics regime, (ii) food security and (iii) economic growth (GDP) in Malawi at important time periods in the evolution of their agricultural policy following independence.

and mounting political pressure for political reforms, the systems crashed in all the three parameters during this period. There was a referendum for change in 1993 calling for a democratic government and concurrently a serious food shortage and sharp decline in the GDP (Figs. 1 and 2). A new democratic government came into power in 1994 hence Malawi again went into a political reorganization phase (α). Food security and GDP crashed at this point. Similarly the drought of 2001–2002 caused serious food shortage and had a knock-on effect in terms of GDP. Politically, this experimental democracy is judged to be in the exploitation (r) phase of the adaptive cycle.

A new political leadership came into power in 2004 signaling yet another political reorganization phase (α). At the same time, there was a serious drought that led to a further sharp decline in food security and the GDP in 2005 leading to a release phase. The hard lessons learnt from the 2004–2005 hunger period caused the government to reorganize itself and reintroduce agricultural input subsidies (FISP) in a more extensive form than previously done. This has led to the current stable political regime with ensuing growth of the food and economic sector. Subsequently, Malawi has registered the highest growth in GDP of 9.7% for a decade in 2008[15].

This assessment using the panarchy model highlights the link between the three indicators of human well-being under discussion. Civil society within the country is not stable unless all three aspects are in the conservation phase (K) of their respective adaptive cycles, as indicated in Figure 5 for the time period 1970–1980s and 2006 to the present. The panarchy model is useful here as it can offer some insight into the future. The model predicts that the conservation phase has inherent low resilience and is therefore likely to crash. This can be avoided or minimized if the tipping points can be recognized and mitigated against early enough. An obvious tipping point in the recent past

has been extreme weather events (droughts and floods) which are predicted to increase as a result of climate change[20]. This analysis would therefore support, as a matter of urgency, initiatives which aim at constructing flood defenses and irrigation systems and reforestation to mitigate drought. Such constructions may have significant effect on the delivery of other ecosystem goods and services, therefore a holistic approach considering the full suite of ecosystem services is recommended.

Conclusion and Recommendations

The analysis conducted in this paper highlights the need to consider all policy options and delivery mechanisms in a holistic manner. At its simplest level, a government might consider the production of agricultural products and the wealth of its citizens as a good indicator of effective governance. However, as suggested by the analysis of ecosystem goods and services conducted here, unless the regulating and supporting services are explicitly considered, the social and economic system will not be sustainable. The framework outlined in Table 2 highlights many different types of services which need to be considered and does not completely fail in data-deficient situations. It can also be used within a decision support system to highlight areas for future monitoring and research. The panarchy approach is useful in order to help understand such complex systems. The current global push for evidence-based policy formulation in democracies requires simple, easily implemented, robust tools and our analysis suggests that panarchy provides a suitable framework.

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Effects of input management and crop diversity on economic returns and riskiness of cropping systems in the semi-arid Canadian Prairie

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Abstract

Producers in the semi-arid Dark Brown Chernozemic (Typic Boroll) soil zone of the Canadian Prairie are contemplating changes to land-use practices, moving away from conventional high-input production systems that specialize in one or two annual grain crops to more diversified and extended cropping systems that use reduced-input and organic management practices. This study examined the economic merits of nine cropping systems, consisting of a factorial combination of three input management methods and three levels of cropping diversity. It was conducted over the 1996–2007 period on a loam soil at Scott, Saskatchewan. The input treatments were: (1) high input (HIGH), which used conventional tillage and full recommended rates of fertilizers and pesticides 'as required'; (2) reduced input (RED), which used conservation tillage and integrated weed and nutrient management practices in an effort to lower requirements for fuel, fertilizers and pesticides; and (3) organic input (ORG), which used tillage, non-chemical pest control, higher seeding rates, delayed seeding and legume crops to replenish soil nutrients. The crop diversity treatments included: (1) a fallow-based rotation with low crop diversity (LOW); (2) a diversified annual rotation of cereal, oilseed and pulse grains (DAG); and (3) a diversified rotation using annual grains and perennial forages (DAP). All crop rotations were 6 years in length. At the 2007 input costs and prices, average net returns and 12-year net present values were higher for organic than for non-organic treatments, with the ORG input/LOW crop diversity system being the most profitable (net returns = \$234 ha^{-1} yr^{-1} and net present value = \$1953 ha^{-1}). Net returns averaged about 10% less for ORG/DAG compared to the most profitable system, and about 22% less for HIGH/DAG and RED/DAG (the best non-organic systems). The DAP treatments that included forage were not economically competitive with the other treatments, often producing economic losses. The relative profitability of the organic treatments was highly dependent on the existence of organic price premiums. When price premiums for organic crops were reduced to less than 70% of the 2007 levels, the organic treatments were less profitable than the comparable non-organic treatments. The organic treatments also experienced significantly lower (and often negative) net returns compared to the non-organic treatments during completion of the 3-year organic certification period. We estimated that it required 5–7 years after completion of certification for the organic treatments to break even with the comparable non-organic treatments. Thereafter the organic treatments produced consistently higher net earnings. Production costs averaged

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16% lower with ORG management compared to the HIGH-input treatments, but we found little difference in total costs between the respective HIGH- and RED-input treatments. The organic treatments also displayed lower income variability than the non-organic treatments, with the ORG/LOW system being preferred by risk-averse producers, who do not subscribe to all-risk crop insurance, and with the ORG/LOW and ORG/DAG systems preferred by low and medium risk-averse producers when having the added financial protection from the Canada/Saskatchewan all-risk crop insurance program.

Key words: crop rotations, conservation tillage, organic farming, reduced input management, production costs, net returns, risk

Introduction

Land-use practices are undergoing significant change throughout the North American Great Plains region in response to rising input costs, expanding global markets and growing concerns over food safety and environmental degradation[1,2]. Producers have begun to extend and diversify their traditional cereal-based cropping systems by reducing summer fallow and including oilseed and legume crops in the rotation, together with increased use of conservation tillage methods, to capitalize on the rotational benefits of mixed cropping systems, reduce the need for synthetic N fertilizer and fossil energy, and protect the quality of the soil, water and air resources[3–5]. Other producers have become increasingly interested in employing low-input and organic production methods to further reduce the reliance on purchased inputs and to add value to the products produced[2,6–8]. The degree to which producers will ultimately adopt these new or alternative production systems depends on their ability to lower production costs, generate increased net returns, or reduce overall financial risk compared to current cropping practices[5]. However, few studies have explicitly examined the relative economic merits of these land-use changes under Canadian Prairie conditions.

The use of minimum-till and no-till practices for annual crop production offers producers the opportunity to increase soil moisture conservation, reduce soil erosion, sequester soil carbon and reduce greenhouse gas emissions compared to conventional tillage practices[9,10]. At the same time, however, these practices pose additional challenges with respect to managing problem weeds and maintaining nutrient availability[11–13]. On the semi-arid Brown (Aridic Haploborolls) and Dark Brown (Typic Boroll) Chernozemic soils, researchers have seldom reported an increase in crop yields when conservation tillage is compared to conventional tillage practices in monoculture cereal rotations[14,15], but when conservation tillage is combined with mixed cereal–oilseed–pulse rotations, consistent yield increases are more common[11,16]. The synergism that occurs between conservation tillage and mixed cropping systems has been attributed to several factors, including enhanced soil moisture availability from improved snow trap, reduced evaporation losses and lower moisture use by some crops (e.g., pulses); improved crop establishment due to better surface soil moisture conditions, particularly for small seeded crops; improved nutrient use efficiency resulting from better synchrony between nutrient release via mineralization of previous crop residues and nutrient uptake by the current crop; and to enhanced control of weeds and other crop pests[13,17]. Results of economic studies of conservation tillage practices in these regions have indicated little or no economic advantage over conventional tillage practices for monoculture cereal and fallow-based cropping systems[18,19]. Although reducing tillage intensity lowers costs for labor, fuel and machine repair and overheads, these savings were generally more than offset by higher expenditures for herbicides and N fertilizer. However, in mixed crop rotations significant economic benefits are often reported with conservation tillage management due to a combination of higher crop yields, production of higher valued crops and, in some cases, lower production costs[5,20,21].

Organic agriculture relies on the use of crop rotations, legume green manure and cover crops, the addition of organic soil amendments such as animal manures and compost, rock phosphate and on tillage to maintain the health of the soil and environmental resources, recover nutrients from lower soil depths and to minimize the influences of crop pests[22]. Organic systems typically produce lower crop yields than conventional cropping systems[6,8,23]. They also often require that producers incur substantial transition costs, such as the investment in soil building crops and/or the addition of organic amendments to enhance soil organic matter levels and replenish soil nutrients, and to make needed changes in machine inventories. Further, they require substantial time and effort to learn and master organic production practices, document the practices used and to discover and secure market opportunities. Organic producers must also endure a 3-year certification period during which they are required to use certified organic seed and management methods, but must sell their grain and forage products at commercial or non-organic prices. However, once certified most organic products can be sold at prices greater than conventionally produced products and these higher revenues, combined with savings in expenditures for inorganic fertilizers and chemicals, may lead to overall improvements in net farm income. Studies that have examined the economic merits of organic agriculture have reported that the main determinants of profitability (compared to conventional agriculture) are the relative crop yields, extent of the cost savings due to the reduced reliance

Table 1. Summary of the nine cropping systems.

Input level[1]	Crop diversity	Crop sequence[2]
High (HIGH)	LOW (fallow-based rotation with low diversity of annual grains)	$Fallow_T$–wheat–wheat–$fallow_T$–canola–wheat
Reduced (RED)		$Lentil_{GM}$–wheat–wheat–$fallow_C$–canola–wheat
Organic (ORG)		$Lentil_{GM}$–wheat–wheat–$lentil_{GM}$–canola[3]–wheat
HIGH	DAG (diversified using cereal, oilseed and pulse grains)	Canola–rye–pea–$barley_M$–flax–wheat
RED		Canola–rye–pea–$barley_M$–flax–wheat
ORG		$Lentil_{GM}$–wheat–pea–$barley_M$/Clover–$clover_{GM}$–canola[3]
HIGH	DAP (diversified using annual grains and perennial forages)	Canola–wheat–$barley_F$–oat[4]/bromegrass + alfalfa–hay–hay
RED		Canola–wheat–$barley_F$–oat[4]/bromegrass + alfalfa–hay–hay
ORG		Canola[3]–wheat–$barley_F$–oat[4]/bromegrass + alfalfa–hay–hay

[1] High input uses conventional tillage and full recommended rates of pesticides and fertilizers as required; reduced input uses conservation tillage, integrated pest and nutrient management, and higher seeding rate practices; and organic input uses organic management methods including non-chemical pest control, legume green fallow, selected application of compost, higher seeding rates and later seeding dates.
[2] $Fallow_T$ = tillage fallow, wheat (*Triticum aestivum* L.), canola (*Brassica. rapa* L. or *B. napus* L.), $lentil_{GM}$ (*Lens culinaris* Medikus) green fallow, $fallow_C$ = chemical fallow, field pea (*Pisum sativum* L.), $barley_M$ = malt barley, $barley_F$ = feed barley, clover = sweet clover (*Melilotus officinalis* L.), $clover_{GM}$ = sweet clover green fallow, rye (*Secale cereale* L.), flax (*Linum usitatissimum* L.), oat (*Avena sativa* L.), bromegrass (*Bromus inermis* Leyss.), alfalfa (*Medicago sativa* L.).
[3] Mustard (*B. juncea* L.) replaced canola in these organic systems beginning in 2001.
[4] The oat underseeded to bromegrass + alfalfa was replaced with alfalfa alone beginning in 2002.

on non-renewable resources and purchased inputs, the supply of unpaid family labor, the existence of price premiums for organic products and the magnitude and duration of reduced income during the organic certification/transition period[2,7,8,24].

The objective of this study was to determine and compare production costs, net returns and the riskiness of nine cropping systems, representing a factorial combination of three levels of input usage (high, reduced and organic) and three levels of cropping diversity (low cropping diversity and intensity, diversified cropping using annual grains and diversified cropping using annual grains and perennial forages). The cropping systems were assessed over a 12-year period (1996–2007) on a Dark Brown Chernozemic soil (Typic Boroll) in the Canadian Prairie.

Materials and Methods

Experimental data

The design and methods for the field experiment have been described previously[25–27]; thus only a summary of aspects pertinent to the economic discussion is presented.

The cropping systems experiment was established in 1994 on gently sloping land (1–3% slope) at the Agriculture and Agri-Food Canada Research Farm at Scott, Saskatchewan (52°22′N; 108°50′W; elevation 713 m). The soil was developed from modified glacial till[28], with a loam texture and surface pH in water paste of 5.4–5.9. Long-term (1931–1990) annual weather conditions at this location are 97 days for frost free period, 1.0°C for temperature, 355 mm for precipitation and 635 mm for potential evaporation. The study area had been cultivated for about 90 years using a cereal–fallow or cereal–cereal–fallow rotation with limited (mainly phosphorus) fertilization. The site was uniformly cropped to barley (*Hordeum vulgare* L.) in 1994 to reduce the residual effects in the soil.

Nine cropping systems, each 6 years in length, were established in 1995. They consisted of a factorial combination of three methods of input management and three levels of cropping diversity (Table 1). The input treatments were: (1) high (HIGH, which used conventional tillage for weed control on fallow areas and for seedbed preparation together with full recommended rates of pesticides and fertilizers 'as required'); (2) reduced (RED, which used conservation tillage, together with legume green fallow to build soil N and higher seeding rates to increase crop competition, in an effort to lower the overall requirements for fuel, fertilizers and pesticides); and (3) organic (ORG, which used organic management methods including conventional tillage, non-chemical pest control, legume green fallow, selected application of compost, higher seeding rates and later seeding dates). The crop diversity treatments were: (1) a fallow-based rotation with low-cropping diversity (LOW); (2) a diversified annual rotation of cereal, oilseed and pulse grains (DAG); and (3) a diversified annual rotation of grains and perennial forages (DAP).

The experiment used a split–split-plot design with input level as main-plots, crop diversity as sub-plots and crop or rotation phase as sub-sub-plots. The experimental site occupies 16 ha, with sub-sub-plots 12.8 m × 40 m in size. All phases of each rotation were present every year and each rotation was cycled on its assigned plots. All treatments were replicated four times.

For the HIGH- and ORG-input treatments, tillage using a cultivator equipped with sweeps and mounted harrow was typically used to prepare the seedbed and to control emerging weeds prior to planting. The RED-input treatments received no pre-seeding tillage, but glyphosate was applied prior to planting. All crops were planted using selected

cultivars based on their suitability to the area, with the same cultivars used with all input and crop diversity treatments for a full 6-year cycle. Seeding rates for most crops were typically one-third higher for ORG and RED than for HIGH-input treatments in an attempt to increase crop competition with weeds[27]. The seeds for the ORG and RED-input treatments were treated with *Penicillium bilaiae*, while field pea, lentil and alfalfa seeds were treated with appropriate N-fixing *Rhizobium* inoculants for all treatments. Non-organic spring wheat, barley and pea seeds were treated with fungicide, whereas non-organic canola seeds were treated with fungicide and insecticide. All plots were seeded with a disc drill with the exception of lentil green fallow, which was seeded with a hoe drill. Planting of the ORG treatments was delayed up to 2 weeks compared to HIGH- and RED-input treatments in an effort to improve control of weeds.

Fertilizers N and P were applied to non-organic crops based on the soil test recommendation guidelines from the Saskatchewan Soil Testing Laboratory[29] for each crop[27]. For the HIGH-input treatments, the same fertilizer rates were applied to all replicates based on the average soil test level of plots for that crop-phase and treatment; for the RED-input treatments, the fertilizer rates varied across replicates based on soil test values for each individual plot and crop type. The N was mid-row banded, while P was placed near the seeds at an average rate of 16 kg P ha^{-1} for all non-organic annual crops. At the end of each 6-year cycle, compost was applied to the RED/DAP and ORG/DAP systems to replace the N removed in the forage and barley crops. The compost was applied and soil-incorporated with tillage between the last forage phase and the subsequent grain phase. The ORG systems utilized legume green fallow to replace some of the N removed in crops, but soil P was not replaced, except where compost was applied.

In-crop weed control for the HIGH-input systems utilized herbicides 'as required' at full recommended rates based on plot surveys of weed populations; RED-input treatments received herbicides only if weed populations exceeded defined threshold values[26]. Organically grown cereals and pea typically received post-seeding harrowing for weed control. Weeds on conventional fallow plots were controlled with tillage using a heavy-duty cultivator with sweeps and mounted harrow. Fallow plots for the RED-input treatments relied on herbicides alone for weed control.

Grain yields were determined at crop maturity by direct harvesting a 1.2 m × 40 m area per plot using a small plot combine. The straw and crop residue from grain crops were chopped and uniformly spread back on the respective plots to protect the soil from erosion and maintain soil quality. Forage yield was determined on a 1.0 m × 40 m area per plot at the soft dough stage of oat and 10% bloom of alfalfa. All grain and forage yields were corrected to a constant 10% moisture basis.

Growing season (1 May–31 August) rainfall, air temperature and other weather parameters were recorded at the test site using an automated weather station and datalogger.

Table 2. Net farm prices ($ t^{-1}) for conventional and organically grown crops.

Crop (% protein)	Conventional	Organic
Spring wheat		
(≤11.99%)	305.14	549.25
(12.0–12.499%)	306.09	550.96
(12.5–12.999%)	307.29	553.12
(13.0–13.499%)	308.59	555.46
(13.5–13.999%)	310.59	559.06
(14.0–14.499%)	313.09	563.56
(14.5–14.999%)	315.49	567.88
(15.0–15.499%)	318.00	572.40
(≥15.5%)	319.34	574.81
Barley feed	214.99	386.98
Barley malt	224.18	403.52
Rye	210.55	–
Canola	555.47	722.11
Mustard	–	983.46
Oat	164.80	296.64
Flax	749.52	–
Pea	325.09	585.16
Hay	81.00	93.15

Economic analysis

The economic analysis follows methods used previously by Zentner et al.[20] and Zentner and Campbell[30]. Spreadsheet programs were developed to determine and compare annual total and unit costs of production, amount and seasonal distribution of resource needs (e.g., seed, fertilizer, pesticides, fuel, machine repair, labor, specialized equipment needs), level of gross and net returns (i.e., income remaining after paying for all cash costs, plus labor and overhead costs for machines and buildings) and riskiness (income variability) for each cropping system. In addition, the net present values (NPV)[31], which incorporate both the timing and magnitude of net returns, were computed for each cropping system using a discount rate of 5%. No allowance was made for investment costs associated with land equity or for differences in management requirements among the treatments. All costs and returns were expressed in Canadian dollars.

The experimental data were extrapolated to the farm-level using a representative farm size of 907 ha and with a typical complement of machinery for each cropping system. Costs for inputs were held constant at their 2007 levels[32,33]. Conventionally produced products were valued at their respective 2007–2008 average farm-gate prices (net of handling, transportation and storage costs) (Table 2). Organically produced products were valued using the relative prices of organic versus conventional grains as established by the Saskatchewan Crop Insurance Corporation[34], such as an organic/conventional price ratio of 1.8 for field pea and cereal crops, 1.3 for canola and 1.5 for

mustard and an assumed organic/conventional price ratio for hay of 1.15. Spring wheat prices were adjusted for protein concentrations obtained in the respective treatments using the 2007–2008 protein price premium schedules as established by the Canadian Wheat Board[35]. Organic price premiums were not permitted for organic products produced in 1996 and 1997 as the hypothetical organic farms were still completing the 3-year organic certification period. The analysis was repeated for five price scenarios reflecting current and possible future declines in organic price premiums: full price premiums received on 100% of the organically grown grains and forage (reflects an established organic farm capable of selling all of its produce at current organic prices); 75, 50 and 25% of current organic price premiums; and no organic price premiums (reflects a new organic producer or one considering the transition from conventional to organic management). The evaluations were conducted with and without participation in the Canada/Saskatchewan all-risk crop insurance program to assess its effectiveness in reducing the overall financial risk associated with the cropping systems. For the former analysis, all grain crops were insured at the 70% yield coverage level for the respective conventional and organic treatments in Risk Area #20 of Saskatchewan[34]; forage and legume green manure crops were assumed to be uninsured.

All findings were expressed on per hectare basis for the complete cropping systems, which includes the costs and returns for all cropped and fallow phases of each treatment. Data for the establishment year of the experiment (1995) were excluded because not all crops were yet in proper sequence, and thus their performance would not be reflective of true treatment effects. All data were initially subjected to analysis of variance on an annual basis for split-split plot designs using Proc Mixed, with the residuals tested for normality with Proc Univariate of SAS[36]. The presence of an excess of zeros in the data created an over-dispersion problem, hence the data were transformed using a gamma distribution[37] and subsequently analyzed using PROC GLIMMIX of SAS Version 9.1[38]. Input and crop diversity levels were modeled as fixed effects. Denominator degrees of freedom for tests of fixed effects were calculated using the Kenward–Roger method. Least square means and standard errors were used in the calculation of least significance differences (LSD) after back-transformation for comparison among treatment means at $P < 0.05$. Riskiness was assessed using stochastic dominance analysis[39] to compare the probability distributions of net returns for each cropping system for groups of producers having low, medium and high risk aversion as defined by Zentner et al.[40].

Results and Discussion

Growing conditions

Growing season (1 May–31 August) precipitation over the 12-year study period averaged 181 mm, which is below the long-term (1961–1990) mean (211 mm) for this region

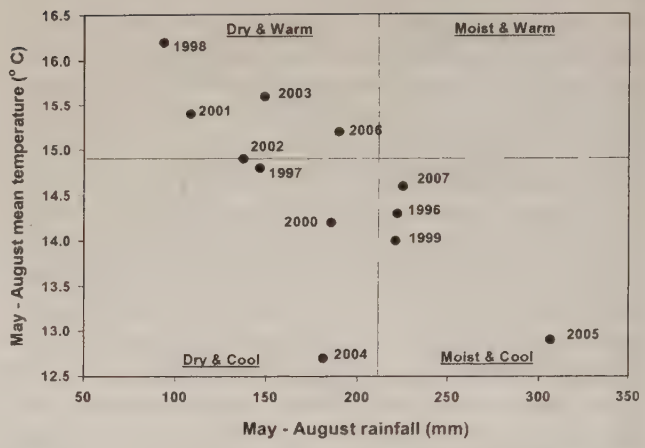

Figure 1. Growing season (May 1–August 31) precipitation and air temperature conditions at Scott, Saskatchewan (1996–2007). Vertical and horizontal lines are the long-term (1961–1990) means for the region.

(Fig. 1)[27]. Growing season temperature averaged 14.6°C compared to the long-term mean of 14.9°C. May to August precipitation was less than 70% of normal in 5 years, with three of these years being consecutive (2001–2003); it was near normal in 6 years, and well above normal in 2005. Overall, five of the growing seasons were categorized as dry and warm, three were dry and cool and 4 years were moist and cool (Fig. 1). The severe drought conditions, particularly in 1998 and 2001–2003, were damaging to crop establishment and development, while an early fall frost in 2004 reduced grain yields and quality. Late summer hail storms also resulted in moderate crop damage in 2005 and light crop damage in 2006.

Production costs

Total costs (excluding crop insurance premiums) were significantly influenced by input level, cropping diversity and the interaction on input level and crop diversity in all years (Table 3). Total costs for the ORG-input treatments averaged \$262 ha^{-1}, which was \$50 ha^{-1} lower (or 16% less) than for the HIGH- and RED-input treatments. There was little difference in total costs for the respective HIGH and RED treatments in most years, despite the intention within the research protocol to reduce the overall reliance on purchased inputs with the RED treatments through use of an integrated approach to nutrient and pest management. Further, total costs were lowest for the LOW crop diversity treatments (\$267 ha^{-1}), and higher but similar for the more intensively cropped DAG and DAP treatments (\$42 ha^{-1} more). Thus, as expected, total production costs were generally lowest for the ORG/LOW and highest for the HIGH/DAG systems. Production costs varied relatively little across years for most treatments (as indicated by the low CVs), but tended to be higher in years with more favorable growing conditions due mainly to the increased costs associated with harvesting, transporting and storing the higher crop yields and the need for additional weed

Table 3. Effect of input management and crop diversity on total annual production costs (without all-risk crop insurance).

Input level/crop diversity	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	Mean	CV[1]
	($ ha^{-1})													%
High input (HIGH)														
Low crop diversity rotation (LOW)	281	289	255	280	325	268	274	252	244	275	270	284	275	7
Diverse annual grains rotation (DAG)	364	367	318	324	408	357	317	334	310	335	385	354	348	9
Grains and forage rotation (DAP)	302	346	265	302	388	332	288	320	288	310	320	329	316	10
Mean (HIGH)	316	334	279	302	374	319	293	302	281	307	325	322	313	
Reduced input (RED)														
LOW rotation	276	258	255	269	298	286	266	290	245	257	304	262	272	7
DAG rotation	338	317	307	313	401	361	303	352	312	329	353	334	335	8
DAP rotation	305	298	267	298	357	311	373	353	330	327	348	332	325	9
Mean (RED)	306	291	276	293	352	319	314	332	296	304	335	309	311	
Organic input (ORG)														
LOW rotation	278	282	282	292	278	231	191	192	250	239	289	237	253	14
DAG rotation	280	281	287	318	273	241	212	213	261	230	262	232	258	12
DAP rotation	280	291	264	303	335	247	237	247	376	244	237	247	276	15
Mean (ORG)	279	285	278	304	295	240	213	217	296	238	263	239	262	
Means														
(LOW rotation)	278	276	264	280	300	262	244	245	246	257	288	261	267	
(DAG rotation)	327	322	304	318	361	320	277	300	294	298	333	307	313	
(DAP rotation)	296	312	265	301	360	297	299	307	331	294	302	303	305	
Input LSD ($P < 0.05$)	32	24	28	16	24	32	12	16	28	24	24	24		
Diversity LSD ($P < 0.05$)	20	16	16	16	16	16	12	12	24	16	16	24		
Input × diversity LSD ($P < 0.05$)	48	28	32	24	32	36	20	24	44	32	32	40		

[1] Coefficient of variation.

control measures for some treatments in these years. By comparison, on the Dark Brown Chernozemic soils in southern Alberta, Smith et al.[7] reported an annual cost saving of 13% with an organically managed spring wheat–legume green fallow rotation compared to a no-till managed spring wheat–fallow rotation, and a 32% cost saving with an organically managed cereal–pulse–oilseed–legume green fallow rotation compared to a no-till cereal–pulse–oilseed–fallow rotation, but a 31% increase in annual costs for an organically managed 4-year mixed grain–forage rotation due largely to the high costs associated with purchasing and applying composted manure to this cropping system. In Ontario, Stonehouse et al.[41] reported that production costs averaged 14, 1 and 21% lower for corn (*Zea mays* L.), soybean (*Glycine max* L.) and fall cereals, respectively, with reduced-input compared to conventional-input management, and 38, 4 and 23% lower relative costs for the respective crops with organic management practices. In the USA, most studies of small grain production have also reported cost savings of up to 49% with organic compared to conventional and reduced tillage systems[42–44].

Expenditures for seed were lowest for the HIGH input/LOW crop diversity treatment ($28 ha^{-1}) due to the high proportion of summer fallow in this rotation; they were highest for the ORG/DAG and ORG/LOW systems ($70 ha^{-1}) reflecting the reliance on legume green manure crops to build soil N fertility, together with the higher seeding rates and higher unit seed costs for the ORG managed grain crops (Table 4). Seed costs for the RED-input treatments were intermediate between the HIGH- and ORG-input treatments, averaging about 33% more than for the HIGH treatments due to the higher seeding rates that were also used with the RED treatments in our study.

Expenditures on inorganic fertilizers, primarily N, were lowest for the LOW crop diversity treatments, reflecting the inclusion of summer fallow or legume green fallow in these rotations (Table 4). Summer fallowing enhances N mineralization from soil organic matter, but frequent use of this practice, particularly when combined with tillage for control of weeds, mines soil fertility by reducing organic matter levels and N supplying capacity of the soil in the long term, and exposes the soil to other environmental damage from wind and water erosion, deep leaching of plant nutrients and enhanced emissions of greenhouse gases[9,10]. The higher fertilizer costs for RED compared to the respective HIGH-input treatments reflects that as soil tillage is reduced with conservation tillage management there is a build-up of crop residues on the surface soil, which slows the rate of residue decomposition, resulting in the temporary immobilization of N until the system reaches a new steady state[45]. Others have also suggested that with no-till management there is greater risk of N loss by denitrification than in tilled systems, especially in wet years[46]. Thus during this transition period, available N in soil is often lower under conservation tillage management than under conventional tillage, resulting in somewhat higher N fertilizer recommendations when based on soil tests[15,21]. In the longer term, however, it is expected that this effect may diminish and could possibly reverse as the relative soil organic matter levels and N-supplying capacity of the soil

Table 4. Effect of input management and crop diversity on production costs by resource category (without all-risk crop insurance, 1996–2007).

Input level/ crop diversity	Seed	Fertilizer[1]	Pesticides	Labor	Operating interest	Other[2]	Fuel and oil	Repairs	Machines and buildings	Total
	($ ha^{-1})									
HIGH										
LOW rotation	27.61	51.00	28.34	13.45	6.02	26.57	31.11	23.14	67.71	274.95
DAG rotation	36.41	78.32	44.94	14.43	7.77	26.57	31.76	24.41	83.65	348.26
DAP rotation	41.71	57.33	27.64	14.90	6.55	26.57	31.81	24.43	85.27	316.21
Mean (HIGH)	35.24	62.22	33.64	14.26	6.78	26.57	31.56	23.99	78.88	313.14
RED										
LOW rotation	42.30	56.41	40.92	11.47	6.38	26.57	20.10	16.11	52.07	272.33
DAG rotation	50.23	75.68	49.29	12.85	7.76	26.57	23.49	18.93	70.63	335.43
DAP rotation	49.10	72.49	33.77	14.22	7.05	26.57	25.58	20.35	76.11	325.24
Mean (RED)	47.21	68.19	41.33	12.85	7.06	26.57	23.06	18.46	66.27	311.00
ORG										
LOW rotation	69.87	0.00	0.00	13.02	5.31	31.51	32.59	24.50	77.10	253.90
DAG rotation	71.07	0.00	0.00	13.20	5.40	31.51	33.03	24.92	78.75	257.88
DAP rotation	65.31	13.69	0.00	14.23	5.32	31.51	31.49	24.57	89.85	275.97
Mean (ORG)	68.75	4.56	0.00	13.48	5.34	31.51	32.37	24.66	81.90	262.58
Means										
(LOW rotation)	46.59	35.80	23.09	12.65	5.90	28.22	27.93	21.25	65.63	267.06
(DAG rotation)	52.57	51.33	31.41	13.49	6.98	28.22	29.43	22.75	77.68	313.86
(DAP rotation)	52.04	47.84	20.47	14.45	6.31	28.22	29.63	23.12	83.74	305.81

[1] Includes compost that was applied to selected crops within the reduced input/grains and forage rotation and the organic input/grains and forage rotation.
[2] Includes land taxes, farm utility costs, plus certification and inspection fees for organic treatments.

build over time with the continued use of conservation tillage management; this may be particularly true when combined with the periodic inclusion of a legume green manure or legume forage crop, as in the LOW and DAP crop diversity treatments[47,48].

Pesticide expenditures averaged $8 ha^{-1} higher for RED- than for HIGH-input treatments, with the cost difference being as large as $13 ha^{-1} for the LOW crop diversity treatments (Table 4). These trends reflect the fact that with conservation tillage management, herbicides were substituted for tillage prior to planting and on summer fallow areas. Other Canadian Prairie studies comparing conventional and conservation tillage practices have reported a several-fold increase in herbicide expenditures with no-till management in 2-year or 3-year cereal–fallow rotations due to the higher cost of controlling weeds on summer fallow areas with herbicides than with tillage[19,20], but they too reported a much smaller increase in herbicide costs when using no-till management together with continuous crop rotations. This latter effect reflects the normally small difference in cost between one pre-seeding herbicide application to control weeds on no-till stubble areas, compared to one, and in some years two, pre-seeding tillage operations to control weeds and to prepare the seedbed on stubble areas with conventional tillage management under semi-arid conditions.

Although differences in labor costs among input treatments were not large, they tended to be lowest for RED, intermediate for ORG, and highest for the HIGH-input treatments (Table 4). Further, labor costs tended to be lowest for the LOW and highest for the DAP crop diversity treatments. However, these costs capture only the direct labor required to conduct field operations and perform other production activities and do not include labor associated with management aspects. Studies of conventional and organic systems in the USA often report higher direct labor requirements with organic systems[44,49] but also report higher management labor input due to the greater need to scout and inspect crops for emerging plant pest and nutrition problems, the increased time to research and devise non-chemical control strategies, and the greater effort and costs required to develop and secure markets for organic products[2,50]. Consequently, our labor cost values likely underestimate the relative total labor requirements of the various cropping systems, particularly for the ORG treatments, and this could become an important factor influencing producers' decisions to adopt organic practices in a real-world scenario, especially as farm size increases or if the operator has limited access to unpaid family labor or is dependent on off-farm employment[2,24,50].

Expenditures for fuel and machine repair were lowest for the RED-input treatments, and higher but generally similar for the HIGH- and ORG-input treatments (Table 4), consistent with findings of other comparable studies of conventional and conservation tillage management practices in western Canada[5,18,21]. In contrast, several US studies have reported higher expenditures for fuel with organic compared to conventional practices due to the heavy reliance of

Table 5. Effect of input management and crop diversity on gross product sales (100% organic price premiums).

Input level/crop diversity	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	Mean	CV[1]
	($ ha^{-1})													%
HIGH														
LOW	674	386	263	889	651	331	113	189	362	539	395	566	447	50
DAG	823	484	417	963	796	259	95	252	415	597	470	808	532	51
DAP	554	311	167	568	476	99	59	105	231	439	306	489	317	58
Mean (HIGH)	684	394	282	807	641	230	89	182	336	525	390	621	432	52
RED														
LOW rotation	578	422	363	720	637	331	104	185	362	436	395	557	424	42
DAG rotation	747	502	450	906	851	298	97	218	371	518	478	744	515	49
DAP rotation	458	314	276	480	426	109	73	102	198	394	310	466	301	50
Mean (RED)	594	413	363	702	638	246	91	168	310	449	394	589	413	46
ORG														
LOW rotation	364	283	394	884	610	351	208	284	557	543	543	829	488	44
DAG rotation	315	214	356	1033	614	332	201	287	571	494	440	762	468	52
DAP rotation	294	239	267	635	414	153	85	148	410	500	407	666	352	53
Mean (ORG)	324	245	339	851	546	279	165	240	513	512	463	752	436	48
Means														
(LOW rotation)	539	364	340	831	633	338	142	219	427	506	444	651	453	43
(DAG rotation)	628	400	408	967	754	296	131	252	452	536	463	771	505	48
(DAP rotation)	435	288	237	561	439	120	72	118	280	444	341	540	323	51
Input LSD ($P < 0.05$)	44	48	55	32	57	ns	9	33	70	42	37	35		
Diversity LSD ($P < 0.05$)	31	21	27	32	44	25	10	20	49	27	40	40		
Input × diversity LSD ($P < 0.05$)	62	57	67	55	85	ns	17	43	ns	56	68	67		

[1] Coefficient of variation.

organic management on tillage for weed control and seedbed preparation[44,51]. The savings in machine-related operating costs with conservation tillage management in our study arise from fewer trips across the field and from using machines with greater capacity and lower draft requirements (sprayer versus cultivator). Machine overhead costs were also lowest for the RED-input treatments and highest for ORG treatments. The savings in machine overhead costs with RED compared to HIGH input arise from eliminating (or reducing) the need for tillage machines, using smaller-sized power units with lower capital investment, and extending the life of machines because of their reduced annual use. Similarly, the higher machine overhead costs for the ORG treatments reflects the greater use and reduced life of tillage equipment plus the need for additional and specialized machines (e.g., rotary hoe for in-crop weed control and manure spreader for compost application) used only with ORG management.

Participation in the Canada/Saskatchewan all-risk crop insurance program (excluding insurance on legume green manure and forage crops) added \$10–15 ha^{-1} to the total annual costs for the LOW crop diversity treatments shown in Table 3. It added \$14–16 ha^{-1} to the total costs for the DAG treatments, and \$5–6 ha^{-1} for the DAP treatments, with the respective ORG crop diversity treatments tending to have the higher total insurance premium costs.

Overall, the savings in labor plus machine-related costs with RED-versus HIGH-input treatments were largely offset by higher expenditures for seed, fertilizers and pesticides, as reported in earlier studies[5,21]. In contrast, the savings in expenditures for inorganic fertilizers and pesticides with ORG management more than offset the higher costs for seed, organic certification and inspections and machine overheads compared to the non-organic treatments.

Gross returns

Gross returns or income earned from the sale of grain and forage (with full price premiums for organic products beginning in 1998) were highest for the cropping systems in 1999 and lowest in 2002 (Table 5), directly reflecting the growing conditions and resulting crop yields[23]. Gross returns were significantly influenced by input level in all years except 2001. In 1996 and 1997 when the organic systems were still completing the 3-year certification period, gross returns were highest for the HIGH and RED (1997 only) input treatments, but in 9 of the remaining 10 years, gross returns for the ORG treatments were equal or modestly higher than those from other input treatments. Overall, however, there was relatively little difference in the 12-year average gross returns among the methods of input management. In contrast, gross returns were influenced by cropping diversity in all study years (Table 5), with the DAG treatments typically providing the highest (in 8 of 12 years) and the DAP treatments the lowest gross earnings. In the drought years, gross returns were generally highest for the LOW crop diversity treatments, reflecting the greater soil moisture reserves for crops grown on

Table 6. Effect of input management and crop diversity on net returns (100% organic price premiums and without all-risk crop insurance payouts).

Input level/crop diversity	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	Mean	SD[1]	NPV[2]
	($ ha^{-1})														
HIGH															
LOW rotation	393	97	8	609	326	63	−161	−63	118	264	125	282	172	213	1584
DAG rotation	459	117	99	639	388	−98	−222	−82	105	262	85	454	184	260	1703
DAP rotation	252	−35	−98	266	88	−233	−229	−215	−57	129	−14	160	1	179	53
Mean (HIGH)	368	60	3	505	267	−89	−204	−120	55	218	65	299	119	214	1113
RED															
LOW rotation	302	164	108	451	339	45	−162	−105	117	179	91	295	152	179	1416
DAG rotation	409	185	143	593	450	−63	−206	−134	59	189	125	410	180	248	1693
DAP rotation	153	16	9	182	69	−202	−300	−251	−132	67	−38	134	−24	162	−154
Mean (RED)	288	122	87	409	286	−73	−223	−163	15	145	59	280	103	194	985
ORG															
LOW rotation	86	1	112	592	332	120	17	92	307	304	254	592	234	202	1953
DAG rotation	35	−67	69	715	341	91	−11	74	310	264	178	530	211	233	1759
DAP rotation	14	−52	3	332	79	−94	−152	−99	34	256	170	419	76	182	570
Mean (ORG)	45	−39	61	546	251	39	−49	22	217	275	201	514	174	200	1428
Means															
(LOW rotation)	260	87	76	551	332	76	−102	−25	181	249	157	390	186	183	1651
(DAG rotation)	301	78	104	649	393	−23	−146	−47	158	238	129	465	192	230	1718
(DAP rotation)	140	−24	−29	260	79	−176	−227	−188	−52	151	39	238	18	163	156
Input LSD ($P < 0.05$)	42	47	53	31	ns	57	8	32	69	40	36	34			
Diversity LSD ($P < 0.05$)	30	21	26	31	43	25	10	19	48	26	39	39			
Input × diversity LSD ($P < 0.05$)	59	55	64	54	ns	66	17	ns	ns	54	66	64			

[1] SD = standard deviation.
[2] Net present value computed using a discount rate of 5%.

summer fallow versus on stubble land[17]. Gross returns averaged $505 ha^{-1} for the DAG treatments, about 10% less for the LOW treatments and 36% less for the DAP treatments. Thus, the HIGH/DAG and RED/DAG systems produced the highest gross returns ($524 ha^{-1}), whereas the HIGH/DAP and RED/DAP systems produced the lowest ($309 ha^{-1}).

The variability in annual gross returns (as measured by CV) tended to be lower for RED compared to the HIGH and ORG input treatments, reflecting the benefit of reducing tillage intensity for enhancing soil moisture conservation[14,15]. Similarly, the relative variability in annual gross returns tended to be lower for the LOW crop diversity treatments compared to DAG and DAP, reflecting the value of including summer fallow or legume green fallow in the rotation to enhance soil moisture reserves, build soil N levels and help control problem weeds compared to continuously cropped systems[15,52,53].

Net returns

Base grain and forage prices. Net returns (i.e., profit or residual income remaining after paying for all production costs) for the cropping systems, and without participation in the Canada/Saskatchewan all-risk crop insurance program, averaged $174 ha^{-1} for the ORG treatments, $119 ha^{-1} (32% less) for HIGH-input and $103 ha^{-1} (41% less) for the RED-input treatments (Table 6). The net earnings were significantly influenced by input level in 11 of 12 years, with economic losses common for most treatments during the drought years. In 1996 and 1997 when the ORG treatments did not yet qualify for organic price premiums, net returns for these treatments were substantially lower (and often negative) compared to the non-organic input treatments, and this reduced income during the certification/transition period is often reported as a major barrier to the adoption of organic practices by non-organic producers[7,24]. After this period, however, the ORG treatments earned the highest net returns in 8 of the 10 years, and shared the top ranking with other input treatments in the other 2 years. Among the non-organic treatments, average net returns were higher for HIGH than for the RED-input treatments in 5 years, lower in 2 years, and similar in 5 years. These latter results are generally similar to those reported in earlier studies comparing conservation and conventional tillage management of monoculture spring wheat and fallow-based cropping systems under Canadian Prairie growing conditions[18,21,53]. Further, our results suggest that the RED-input treatments, which also included use of a more integrated approach to pest and nutrient management problems, were generally less profitable than the HIGH-input treatments, which used a more conventional approach of performing tillage operations and applying full recommended rates of

pesticides and inorganic fertilizers as required. These latter findings differ from those by Smith et al.[54] who reported an economic advantage from using integrated weed and nutrient management practices over conventional high-input practices for cereal–oilseed and cereal–pulse cropping systems in this region. However, their 4-year study was conducted during the period of severe drought (1999–2002) when lack of moisture may have prevented full expression of the benefits from high inputs of fertilizers and herbicides.

Net returns were also influenced by crop diversity in all years, with the input by crop diversity interaction significant in nine of these years (Table 6). Net returns averaged $\$189\,ha^{-1}$ for the DAG and LOW cropping systems, but only $\$18\,ha^{-1}$ for the DAP systems. The LOW crop diversity treatments had the highest net earnings (or lowest losses) in the drought years (2001–2003), whereas DAG had the highest net returns in 5 years (1996, 1998, 1999, 2000 and 2007). In the remaining 4 years there was no difference in the net returns for the DAG and LOW crop diversity treatments. Net returns were lowest for the DAP treatments in all years, reflecting the low forage yields obtained in most years due to poor stand establishment when using a companion crop in years with below-normal precipitation and the relatively low price for forage compared to grain crops. This is consistent with the general findings reported for conventional and organically managed grain and grain-forage rotations in southern Alberta[7] and with results from an earlier study of conventional mixed grain and grain-forage rotations at the Scott location[53]. Overall, the most profitable treatment combination was LOW crop diversity with ORG input management (average $\$234\,ha^{-1}$). This was followed closely by DAG with ORG management (about 10% less than the best system) and then by the DAG systems with HIGH and RED inputs (about 22% less) (the best non-organic treatments). The least profitable cropping system was DAP crop diversity with RED input with an average net loss of $\$24\,ha^{-1}$.

The rankings of treatments were largely unchanged when based on the 12-year net present values, which incorporate the time value of money (Table 6). The ORG/LOW system ranked highest in terms of net present value, followed by the three DAG treatments with values that averaged about 12% less than for the best system. The length of time required for the ORG treatments to break even with the comparable non-organic systems (i.e., years required to provide equal accumulated net returns) was about 6 years after organic certification was completed for the LOW crop diversity rotation (i.e., in year 2003), 7 years for the DAG rotation (year 2004) and 5 years for the DAP rotation (year 2002). By comparison, in southern Alberta, Smith et al.[7] reported that the time required to break even compared to the respective conventional rotations under the most likely organic price premium scenario was 8 years for a 2-year spring wheat–legume green fallow rotation, 1 year for the 4-year spring wheat–pulse–oilseed–legume green fallow rotation, while the organically managed 4-year mixed grain–forage rotation would never break even with the comparable conventionally managed rotation. Further, they reported that average net returns under this same price scenario were highest and generally similar for the organically managed spring wheat–pulse–oilseed–legume green fallow rotation and for conventional continuous spring wheat. The organically managed 2-year spring wheat–legume green fallow rotation ranked second highest, and was significantly more profitable than the conventional 2-year spring wheat–fallow rotation. The organic and conventional mixed grain–forage rotations produced economic losses, as was also found in our study. Most US studies have also reported similar or higher net earnings with cropping systems that use organic versus conventional management; however, the relative profitability depended greatly on whether transition costs from conventional to organic management practices, price premiums for organic products and unpaid family labor were included in the calculations[2,43,44,50,51].

Year-to-year variability in net returns in our study was lowest for the ORG input treatments (CV = 115%), compared to a CV of 176% for HIGH and 186% for RED input treatments. Similarly, net income variability was lowest for the LOW crop diversity treatments (CV = 98%), compared to a CV of 120% for DAG and over 900% for DAP, due largely to the low mean net return values for the DAP treatments. The lower income variability for the LOW crop diversity treatments reflects the advantage of fallow-based rotations in stabilizing net farm income compared to continuously cropped systems in this water-constrained region[20,30].

Participation in the Canada/Saskatchewan all-risk crop insurance program increased the annual net returns for the treatments by an average of $\$21\,ha^{-1}$ (range of $\$10–\$37\,ha^{-1}$), with the increases tending to be larger for the DAG treatments (Table 7). The LOW crop diversity treatments received significant payouts from the program in 3–4 years compared with 4–5 years with the DAP treatments and 6–7 years with DAG. However, the overall rankings of the treatments based on the mean annual net returns and net present values changed relatively little compared to the no crop insurance situation. The main impact from participation in the all-risk crop insurance program was to reduce the frequency and magnitude of the economic losses, particularly in the drier years, which helped reduce the year-to-year variability in net returns. For example, the CV values for the ORG-input treatments (averaged across crop diversity levels) declined by about 25 percentage points with participation in the program compared to a decline of about 52 percentage points for the HIGH- and RED-input treatments. Similarly, the decline in the CV values with participation in the program (averaged across input levels) was about 24 percentage points for the LOW crop diversity treatments, 35 for DAG and over 450 percentage points for the DAP treatments. The lower net income variability with all-risk crop insurance reduces the

Table 7. Effect of input management and crop diversity on net returns (100% organic price premiums and with all-risk crop insurance payouts).

Input level/crop diversity	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	Mean	SD[1]	NPV[2]
	($ ha^{-1})														
HIGH															
LOW rotation	383	92	52	599	316	76	−59	12	127	255	119	272	187	185	1716
DAG	450	127	132	625	377	−15	−63	5	128	263	93	438	213	216	1957
DAP	245	−34	−54	262	83	−178	−167	−160	−38	123	−13	155	19	154	206
Mean (HIGH)	359	62	43	495	259	−39	−96	−48	72	214	66	288	140	182	1293
RED															
LOW rotation	293	158	105	441	329	55	−60	−29	122	174	84	285	163	150	1506
DAG rotation	397	187	156	579	436	4	−50	−35	92	202	135	393	208	202	1925
DAP rotation	147	13	13	176	79	−158	−247	−192	−104	66	−38	129	−10	140	−31
Mean (RED)	279	119	91	399	281	−33	−119	−85	37	147	60	269	120	161	1133
ORG															
LOW rotation	73	−8	137	579	318	178	194	213	312	351	241	575	264	179	2199
DAG rotation	33	−57	109	701	366	143	157	178	314	333	183	517	248	211	2078
DAP rotation	10	−58	−1	327	73	−71	−87	−58	40	282	164	413	86	171	653
Mean (ORG)	39	−41	82	536	252	83	88	111	222	322	196	502	199	179	1643
Means															
(LOW rotation)	250	81	98	540	321	103	25	65	187	260	148	377	205	152	1807
(DAG rotation)	293	86	132	635	393	44	15	49	178	266	137	449	223	190	1987
(DAP rotation)	134	−26	−14	255	78	−136	−167	−137	−34	157	38	232	32	143	276
Input LSD ($P < 0.05$)	44	37	30	30	ns	33	4	22	58	39	31	35			
Diversity LSD ($P < 0.05$)	28	18	18	31	41	13	5	11	43	24	34	38			
Input × Diversity LSD ($P < 0.05$)	59	44	39	53	ns	38	8	26	ns	52	57	64			

[1] SD = standard deviation.
[2] Net present value computed using a discount rate of 5%.

overall riskiness of the cropping systems, a benefit to producers who are risk averse[30].

Note, however, that our findings with respect to participation in the all-risk crop insurance program may overstate the impact on net returns for the cropping systems. For example, in our analysis, crop yield guarantees were held constant throughout the 12-year study period, as were the annual insurance premium costs for crops. However, in reality, producers who are operating on an individual farm coverage basis would have their yield guarantee levels for crops adjusted annually based on their historical 10-year moving average yields. At the same time, their annual insurance premium costs would also be adjusted based on these coverage levels and their past record of claims. Nevertheless, our findings serve to illustrate the relative benefits of all-risk crop insurance in protecting against significant net income declines (or losses) in drought years, and in helping to reduce the overall riskiness associated with adopting new or alternative cropping systems.

Effect of changes in organic price premiums. Changes in the price premiums received for organic products had a major impact on net returns and the overall rankings of the ORG treatments (Fig. 2). For example, when the organic price premiums were reduced by 25% from current levels, average annual net returns for the ORG-managed LOW, DAG and DAP crop diversity treatments declined by $51, $52 and $31 ha^{-1}, respectively. Similarly, if there were no price premiums for organic products, net returns for the respective ORG treatments declined by $204, $208 and $122 ha^{-1}, making them the least profitable cropping systems. As reported earlier, at full price premiums for organic crops, the ORG treatments were significantly more profitable than the respective HIGH- and RED-input treatments, with the ORG/LOW system being the most profitable. However, when the organic price premiums were reduced to less than about 70% of the base values, HIGH/DAG was the overall most profitable cropping system.

Within the LOW crop diversity treatments, reductions in the organic price premiums of up to 35% with all-risk crop insurance, and reductions of up to 30% without all-risk crop insurance, could be tolerated before the profitability of the ORG/LOW system declined below that of the HIGH/LOW system (i.e., the best non-organic system within this crop diversity level) (Fig. 2). In contrast, within the DAG crop diversity treatments, the organic price premiums could only decline by about 13% with all-risk crop insurance and by about 8% without all-risk crop insurance, before HIGH/DAG and RED/DAG replaced ORG/DAG as the most profitable cropping systems. Likewise, within the DAP crop diversity treatments, the organic price premiums could decline by as much as 60–65% before ORG/DAP became less profitable than HIGH/DAP. These differences in threshold values among crop diversity levels reflect the

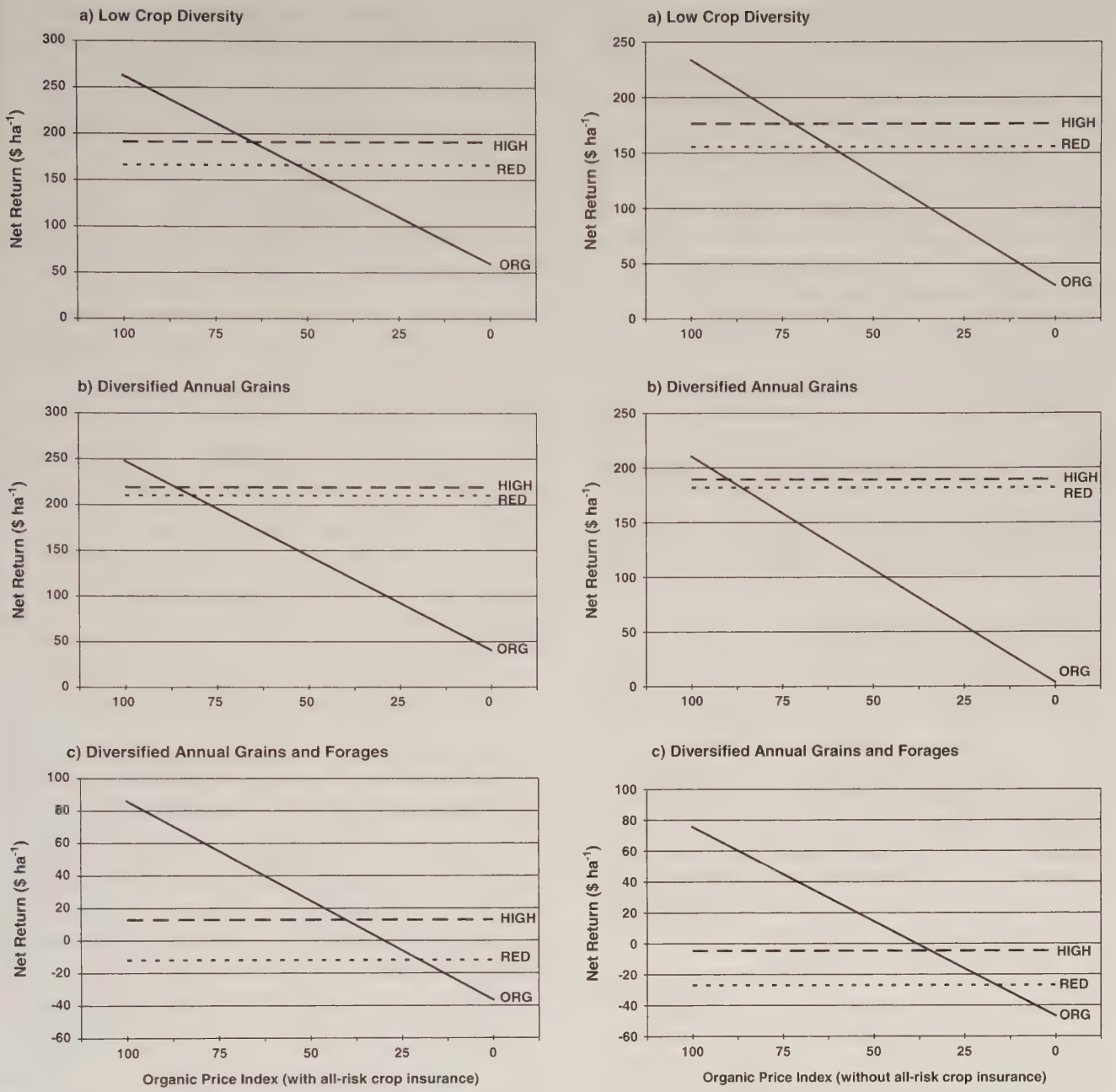

Figure 2. Effect of changes in the price premiums for organic products on mean net returns of cropping systems, with and without all-risk crop insurance (1996–2007) (HIGH = high input, RED = reduced input and ORG = organic input).

relative profitability of the respective organic and non-organic treatments. For example, when the difference in net returns between an organic and non-organic treatment is initially positive and large (as in the case for LOW and DAP), the organic treatment can accommodate a much larger reduction in the organic price premiums before its profitability level and rank order fall below that of the non-organic treatment, compared to when the difference in net returns between treatments is small (as in the case of DAG). This dependency of the ORG treatments on price premiums raises a concern about the long-term economic viability of organic practices if an increasing number of producers convert from conventional to organic production methods, particularly if the demand for organic products does not keep pace with rising supplies.

These results are in general agreement with those of Smith et al.[7] who reported that the relative profitability of the organic cropping systems in southern Alberta were highly conditional upon the existence of sizable and sustained price premiums for organic produce. Several US studies have also reported similar findings[44,51,55]; but, others report that organic production practices can be equally or be more profitable than conventional practices even without price premiums for organic products[50,56].

Table 8. Risk efficient cropping systems[1] for selected crop price and all risk crop insurance scenarios.

Crop price/input cost	All-risk crop insurance	Level of risk aversion		
		Low	Medium	High
(i) Base crop prices				
All treatments[2]	No	ORG/LOW	ORG/LOW	ORG/LOW
	Yes	ORG/LOW; ORG/DAG	ORG/LOW; ORG/DAG	ORG/LOW
Non-organic treatments only[3]	No	HIGH/DAG; HIGH/LOW	HIGH/LOW	HIGH/LOW
	Yes	HIGH/DAG; HIGH/LOW; RED/DAG	HIGH/DAG; HIGH/LOW	HIGH/LOW
(ii) 25% decline in organic crop prices				
All treatments	Yes	ORG/LOW; HIGH/DAG; RED/DAG	ORG/LOW; HIGH/LOW	ORG/LOW; HIGH/LOW
(iii) 50% decline in organic crop prices				
All treatments	Yes	HIGH/DAG; HIGH/LOW; RED/DAG	HIGH/DAG; HIGH/LOW	HIGH/LOW

[1] HIGH = high input, RED = reduced input and ORG = organic input, while LOW = fallow-based rotation with low crop diversity; DAG = diversified annual rotation of cereal, oilseed and pulse grains; and DAP = diversified rotation using annual grains and perennial forages.
[2] Comparisons of the cumulative probability distributions of net returns were completed among all cropping treatments.
[3] Comparisons of the cumulative probability distributions of net returns were completed among non-organic treatments only.

Riskiness of cropping systems

Decision making in risky situations, as in choosing among cropping systems, often requires making a trade-off between the potential to earn higher net returns on one hand and having to accept a higher level of income variability (risk), on the other hand[5]. The amount of income variability or risk that producers are willing to accept depends on their personal preferences, attitudes towards risk and financial situation[57]. Producers who are less willing to gamble (i.e., more risk averse) will often forego production opportunities that offer the possibility of significant increases in net return but higher income variability, for those that offer lower net returns but also lower risk.

Based on comparisons of the cumulative probability density functions of net returns among all treatments using stochastic dominance principles[39], risk-averse producers would typically choose only the ORG/LOW cropping system when crop prices were at the base levels and without the protection of all-risk crop insurance (Table 8). Under this same crop price scenario but with participation in the all-risk crop insurance program, producers who have the lowest aversion to risk would also consider choosing the more intensively cropped ORG/DAG system. These findings differ from those reported in Alberta by Smith et al.[7] who determined that the organic treatments had slightly higher financial risk than the conventionally managed rotations. In contrast, in southwestern Minnesota, Mahoney et al.[51] did not find net returns to be more variable or risky with organic production methods, whereas Hanson et al.[58] reported that in southeastern Pennsylvania an organic cash grain rotation was preferred by risk-averse producers over a conventional corn–soybean rotation.

When comparisons of the probability distributions were made only among the non-organic treatments, producers with low risk aversion and who participate in all-risk crop insurance would choose either HIGH/DAG or RED/DAG systems, whereas those who do not subscribe to all-risk crop insurance would choose HIGH/DAG or HIGH/LOW (Table 8). Non-organic producers with medium risk aversion would also choose HIGH/DAG or HIGH/LOW, whereas those who are even more risk averse would choose only the HIGH/LOW system with its high proportion of summer fallow. Historically, frequent summer fallowing has been the main management practice used by producers in semi-arid regions to stabilize crop yields and farm income[17]. These findings are in general agreement with those reported in earlier studies of conventionally managed cropping systems in the study area[20,30].

When the price premiums for organic products were reduced by 25% (holding conventional crop prices and input costs at base levels), HIGH/DAG and RED/DAG were included along with ORG/LOW as the preferred cropping systems by producers with low risk aversion, whereas HIGH/LOW and ORG/LOW were preferred by medium and high risk-averse producers. When organic price premiums were reduced by 50% or more, the organic systems were no longer risk efficient or preferred by producers. The DAP systems, with their low annual net returns and high relative income variability would not be chosen by risk-averse producers under any of the economic scenarios examined.

Conclusions

As input costs rise and product prices decline, producers look for alternative cropping opportunities to enhance net farm income through lowering production costs, adding value to products produced or reducing the risk of financial

loss. On the Canadian Prairies, conservation tillage and the use of reduced input and organic management practices, together with diversifying crop rotations, are being promoted as new opportunities for producers with beneficial environmental effects, but relatively little is known about how these newer cropping systems rank in terms of their economic performance compared to current practices. To evaluate this issue we compared a matrix of nine dryland cropping systems for a Dark Brown Chernozemic soil (Typic Boroll). The study examined three levels of input use [conventional high inputs (HIGH); reduced inputs (RED) where we tried to lower the requirements for fertilizers, fuel and pesticides; and organic inputs (ORG)] in a factorial combination with three levels of cropping diversity [a fallow-based rotation with low crop diversity (LOW); a diversified annual rotation of cereal, oilseed and pulse grains (DAG); and a diversified rotation of annual grains and perennial forages (DAP)]. Our findings indicated that:

(1) The most profitable cropping system over the 1996–2007 period, with the current organic price premiums of 30–80% over conventional crop prices, was the ORG-input/LOW crop diversity systems. This was followed closely by ORG/DAG (10% less), and then by HIGH/DAG and RED/DAG (22% less) (the best non-organic systems). The mixed grain–forage rotations (DAP) were not economically competitive with the grain-only treatments.

(2) Net returns for the organic treatments were much lower and sometimes negative during the certification period in contrast to the non-organic treatments. We estimated that it would take 5–7 years beyond completion of the 3-year certification period for the ORG treatments to recoup this foregone income. Thereafter, the ORG treatments were consistently more profitable than the non-organic treatments. This reduced income during the transition from conventional to organic management may create cash flow and loan repayment challenges for producers with limited access to credit or those who need to make adjustments or additions to their machine inventories to accommodate organic practices.

(3) The relative profitability of the organic treatments was highly dependent on the existence of significant price premiums for the organic products. When the organic price premiums were reduced to less than 70% of the 2007 levels, the organic treatments were less profitable than the non-organic treatments. This calls into question the long-term economic viability of the organic management practices if more and more producers move to organic management, unless demand for organic products keeps pace with the increasing supply or producers find other ways to add additional value to their products (e.g., packaging and selling products in smaller quantities versus in bulk, or processing raw crop products into finished food products).

(4) Among the non-organic treatments, net returns were highest for HIGH-input/DAG and RED-input/DAG, with net returns averaging about 11% less for the comparable LOW crop diversity systems. At the same time, production costs were higher for the DAG compared to LOW crop diversity systems, but we did not find significant savings in total costs for RED-input versus HIGH-input management. Nevertheless, these findings suggest that area producers can profitably reduce the damaging effects to the soil and environment from use of traditional production practices by substituting herbicides for tillage in weed control and by substituting legume green fallow for conventional summer fallow.

(5) Income variability was lower for the organic than the non-organic treatments and would be preferred by most risk-averse producers. Participation in the Canada/Saskatchewan crop insurance program was effective in reducing, but not eliminating, the additional risk associated with adopting more intensive and diversified cropping systems. In the end, producers considering changes to their cropping systems will need to weigh the tradeoff between the potential to increase net earnings and the need to accept additional financial risk. The value of this study is that it provides some guidance in making these economic decisions.

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Effect of feeding system on unsaturated fatty acid level in milk of dairy cows

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Abstract

In recent years, consumer attitudes toward fat of animal origin have changed owing to findings that some milk fatty acids (FAs) are positive for human health, especially conjugated linolenic acid and *n*-3 FAs. Accordingly, the manipulation of the fat content and FA composition of cows' milk via nutritional strategies has been an important target for the dairy industry in many countries. Twenty commercial Holstein–Friesian dairy herds of Asturias (northern Spain) with 1106 dairy cows were examined in order to evaluate milk FA profiles under different management systems. These herds were divided into three groups according to management: (1) indoor herds: cows feeding indoors, (2) mixed herds: indoor management system but with at least 6 h of grazing outdoors and (3) outdoor herds: cows allowed 6–18 h of grazing per day. Milk from the indoor herds exhibited the highest concentration of fat (3.57%; $P \leqslant 0.01$), protein (3.14%; $P \leqslant 0.001$), lactose (4.76%; $P \leqslant 0.01$) and urea (29.4 mg dl^{-1}; $P \leqslant 0.01$). The milk of outdoor herds had a lower ($P \leqslant 0.05$) content of short-chain FAs than that of the indoor and mixed herds (10.89 versus 11.52 and 11.35 g 100 g^{-1} FA). The milk of the indoor herds had higher concentrations of saturated fatty acids (SFA) (67.56 g 100 g^{-1} FA; $P \leqslant 0.001$) and palmitic and palmitoleic acids (30.16 and 1.82 g 100 g^{-1} FA, respectively), while that of the mixed and outdoors herds had higher concentrations of unsaturated fatty acids (UFA) (34.58 g 100 g^{-1} FA; $P \leqslant 0.001$) and long-chain FAs, especially stearic (13.89 g 100 g^{-1} FA; $P \leqslant 0.01$), vaccenic (2.77 g 100 g^{-1} FA; $P \leqslant 0.001$), conjugated linoleic (0.92 g 100 g^{-1} FA; $P \leqslant 0.001$) and linolenic (0.42 g 100 g^{-1} FA; $P \leqslant 0.001$) acids. Results from this study suggest that the incorporation of forage and pasture in the diet of dairy cows can improve the FA profile of milk.

Key words: pasture, dairy cow, milk quality, fatty acids

Introduction

Since the entry of Spain into the European Union in 1986 and the adoption of the milk quota system, the country has seen a large reduction in the number of dairy farms. Between 2001 and 2008, there has been a 55% reduction in the number of dairy farms in Spain, from 53,224 to 24,133. This trend in dairy production along the Atlantic Coast of Spain, which accounts for 79% of the milk quota holders, has followed the national trend[1]. While there has been a dramatic reduction in the number of milk quota owners, accompanied by a limited reduction in the number of cows milked, average milk production of remaining farms has experienced a large increase. Genetically improved dairy cattle usually make up the herds of these remaining producers, who have increased the percentage of concentrates in the feed[2].

Since the cost of inputs (labor, cows, feed, etc.) has increased, but the price of milk and milk products has remained steady or even declined, farmers need to become more efficient to remain profitable. Grazing has been proposed as an essential strategy for the efficient use of pastoral resources which are abundant in damp, temperate areas. Northern Spain has a marine west coast climate, generally warm and wet summers, and fairly mild winters. Annual rainfall is above 900 mm and the mean annual

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temperature is approximately 13°C. These climatic conditions allow annual grazing, which have been used traditionally across Atlantic Europe.

Milk contains a high proportion of saturated fatty acids (SFA; 70–75%), which has made it target of criticism by diet and nutrition experts[3]. However, about 2% of milk fatty acids (FA) are polyunsaturated fatty acids (PUFA), including *n*-3 FAs, rumenic and vaccenic acids[4], which have health benefits for consumers[5]. Increasing the concentration of desirable FAs in ruminant products has received greater attention recently[6]. Fresh grass contains a high proportion of its total FA content in the form of C18:3. Cows grazing fresh grass produce milk with improved acid profiles for human health, as shown by a higher proportion of PUFA, especially conjugated linoleic acid (CLA) and linolenic acid[7,8]. Moreover, pasture feeding imparts agreeable sensorial qualities to milk: grassy flavors can be easily recognized by some consumers[9]. Accordingly, feeding fresh forage extends the role of grazing as a natural and sustainable production system with potential health benefits.

The aim of this study was to examine milk characteristics among dairy herds along the Atlantic Coast of Spain (Asturias). Information from the study sought to elucidate differences in FA profiles of milk fat from representative feeding methods, thereby identifying potential value-added attributes of milk.

Materials and Methods

The milk of 20 commercial Holstein–Friesian dairy herds from northern Spain was examined in spring of 2008. All herds were enrolled in a routine dairy control program (run by Asturiana de Control Lechero, S. Coop. L.) consisting of regular monitoring of milk yield and quality, and cow reproduction and health (Table 1). The total number of dairy cows making up these herds was 1106, approximately 1.25% of all dairy cows in Asturias.

All farms prepared the total mixed ration (TMR) in a mixer-wagon. The selected herds were divided into three groups according to their management: (1) Indoor herds ($n = 10$): representing the conventional production and feeding system now used in the Atlantic arc. These herds were fed TMR with grass and maize silages plus cereals at a concentrate : forage ratio of 1 : 1. (2) Mixed herds ($n = 4$): representing a system with low use of preserved forage and a high input of concentrates and by-products. The cows of these farms grazed for up to 6 h per day. (3) Outdoor herds ($n = 6$): representing a low-input system. These cows grazed between 6 and 18 h per day. Low levels of concentrate were included in the TMR in these herds. Obtaining additional representative farms using grazing and mixed feeding regimes was difficult due to an unwillingness of local producers to be involved in the study. Consequently, the numbers of herds in each treatment was unbalanced.

Milk bulk tanks were sampled weekly from April to June 2008. Milk samples were taken from the bulk tank after stirring following at least two milkings at each participating farm. One sample of freshly made TMR was taken fortnightly from April to June along the feeders from each farm. Before the cattle moved to each new plot for grazing, the farmers sampled the pasture of this new plot by cutting 1 kg of the grass with a hand mower to a height of 6 cm from four different areas chosen at random. Rotational grazing management resulted in a change of plot every 2–3 weeks, allowing a total of 46 samples of grass. All samples were kept refrigerated and analyzed immediately upon arrival at the laboratory.

Table 1. Differences in production variables (means ± standard error) and proportion of feed used in each management system. Data are based on farm records and survey responses from a questionnaire.

Herd characteristics	Indoor	Mixed	Outdoor
Number of farms	10	4	6
Herd size (milking cows)	57 ± 10.8	37 ± 17.0	65 ± 13.9
Milk yield per cow (kg lactation^{-1})	9715 ± 351	8504 ± 544	8631 ± 453
TMR intake (kg fresh matter d^{-1})	45.6 ± 2.46	47.5 ± 6.95	31.6 ± 3.48
Proportion of farms using the indicated feed			
Fresh forage	0.00	1.00	1.00
Maize silage	0.90	0.25	0.50
Grass silage	1.00	0.25	0.83
Grass hay	0.50	0.00	0.00
Alfalfa	0.40	0.00	0.00
Straw[1]	0.30	0.00	0.17
Cereals[2]	1.00	0.75	0.83
By-products[3]	0.00	0.50	0.00

[1] Wheat, barley and/or oat.
[2] Mixed concentrate feeds.
[3] Sugar beet pulp or apple pulp.

All feed samples were dried (60°C for 24 h) and ground through a 0.75-mm mesh. The nutritive parameters were determined by near infrared spectroscopy (FOSS NIRSystem 5000, FOSS NIRSystems, Inc., Laurel, MD, USA). Milk samples were analyzed for fat, protein, urea and lactose contents by Fourier Transform Infrared in accordance with AOAC standards (MilkoScan FT 6000, FOSS NIRSystems, Inc.).

The FA content of the feeds was analyzed according to Sukhija and Palmquist[10] using modifications of Palmquist and Jenkins[11]. For milk FA analysis, fat was isolated as described by Feng et al.[12] and transesterified as described by Christie[13] with modifications of Chouinard et al.[14]. FA methyl esters were determined by gas–liquid chromatography (Varian 4000 GC/MS, Varian Inc., Palo Alto, CA, USA) in both milk and feed samples. Methyl esters were separated using a 100 m × 0.25 mm i.d. fused silica capillary column (CP-Sil 88 Varian). Individual FA peaks were identified by comparison of their retention times and mass spectra with those of pure methyl ester standards (Matreya Inc., PA, USA and Sigma-Aldrich Inc., MO, USA).

Table 2. Chemical composition (% dry matter basis) and FA profiles of the feed and pasture under different herd management systems.

	TMR					Pasture			
	Indoor	**Mixed**	**Outdoor**	**SEM**[1]	***P***	**Mixed**	**Outdoor**	**SEM**[1]	***P***
Dry matter (DM)	47.7	48.7	49.8	1.26	NS	15.0	15.3	0.96	NS
Organic matter	90.5	90.3	91.3	0.17	NS	89.7	90.8	0.32	NS
Crude protein	16.4[a]	14.2[b]	12.7[c]	0.23	***	20.0	20.7	1.72	NS
Neutral detergent fiber	43.4	46.9	46.4	0.58	NS	44.3	39.3	1.08	NS
Acid detergent fiber	23.0[b]	25.1[ab]	27.5[a]	0.36	***	22.2	20.4	0.76	NS
Crude fat	4.46[a]	3.72[b]	3.69[b]	0.088	**	2.70	3.54	0.306	NS
Starch	16.5	16.7	17.1	0.44	NS	ND[2]	ND	–	–
Net energy (Mcal kg^{-1} DM)	1.24	1.19	1.21	0.006	NS	1.65	1.74	0.029	NS
Fatty acids (g $100\,g^{-1}$ FA)									
C6:0	0.10	0.24	0.22	0.029	NS	0.36	0.25	0.063	NS
C8:0	0.20[b]	0.68[a]	0.19[b]	0.040	*	0.09	0.03	0.015	NS
C10:0	0.05[b]	0.21[a]	0.07[b]	0.003	***	ND	ND	–	–
C12:0	0.33	0.47	0.30	0.026	NS	0.12	0.13	0.036	NS
C14:0	0.85[b]	1.53[a]	1.00[b]	0.045	**	0.38	0.38	0.041	NS
C15:0	0.05	0.06	0.07	0.003	NS	ND	ND	–	–
C16:0	35.98	34.85	29.00	1.283	NS	23.16	26.30	1.510	NS
C16:1	0.20[b]	0.19[b]	0.30[a]	0.006	**	0.16	0.36	0.133	NS
C17:0	0.09	0.07	0.07	0.005	NS	0.09	0.2	0.018	NS
C17:1	0.001	0.007	ND	0.001	NS	ND	ND	–	–
C18:0	2.97[a]	2.85[a]	1.31[b]	0.184	*	1.55	0.88	0.224	NS
C18:1 *cis*9	27.34[a]	27.33[a]	18.84[b]	0.562	**	2.77	2.76	0.363	NS
C18:2 *cis*9 *cis*12	27.59[b]	26.17[b]	42.98[a]	1.776	*	16.86	15.70	1.585	NS
C18:3 *cis*9 *cis*12 *cis*15	4.13	2.85	5.58	0.370	NS	45.24	52.08	3.700	NS
C20:0	0.13	0.12	0.08	0.013	NS	0.37	0.22	0.031	NS
C20:2	0.002	ND	ND	–	–	ND	ND	–	–
C22:0	0.001[b]	0.013[a]	0.000[b]	0.001	**	0.23	ND	–	–

[a,b,c]Means in a row with unlike letters differ significantly. *$P < 0.05$, **$P < 0.01$, ***$P < 0.001$, NS: not significant.
[1] SEM, standard error of the means.
[2] ND, not detected.

Feedstuff and milk data collected over 12 weeks were analyzed using a GLM procedure for unbalanced ANOVA. The statistical analysis was preformed using the SAS statistical package[15] according to the model:

$$Y_{ijk} = \mu + M_i + W_j + H_k + E_{ijk},$$

where Y_{ijk} is the dependent variable, μ is the overall mean, M_i is the effect of management system, W_j is the week of sampling, H_k is the effect of the herd and E_{ijk} is the residual error. Significant differences were accepted if $P \leqslant 0.05$.

Results

Chemical composition of feedstuffs and pasture

No differences were observed between farms in terms of the dry matter, organic matter, neutral detergent fiber, starch or net energy contents of TMR (Table 2). The TMR for indoor herds had higher crude protein and crude fat contents and a lower acid detergent fiber content than the TMR for the mixed and outdoor herds. Nearly 90% of the FA of the feedstuffs was composed of palmitic (C16:0), oleic (C18:1 *cis*9) and linoleic (C18:2 *cis*9 *cis*12) acids. The TMR given to the mixed herds had higher concentrations of caprylic (C8:0), capric (C10:0) and myristic (C14:0) acids than that given to the indoor and outdoor herds, and had a lower C16:1 content than outdoor herd TMR. The outdoor herds' feed showed a higher proportion of linoleic and lower stearic (C18:0) and oleic acid contents than those of the mixed and indoor herds. The chemical composition of the pasture was similar between mixed and outdoor systems, and was typical for the region during a wet spring[16]. The predominant FAs in pasture were linolenic (C18:3 *cis*9 *cis*12 *cis*15), palmitic and linoleic acids, which comprised nearly 90% of total FA measured.

Milk composition and FAs profile

Indoor herds showed the highest concentration of protein, fat, lactose and urea (Table 3). The indoor and mixed herds produced milk with a higher content of short-chain FAs compared to the outdoor herds (11.52 and 11.35 versus 10.89 g $100\,g^{-1}$ FA, respectively; $P \leqslant 0.05$). Saturated medium-chain FA concentration of the indoor and mixed herd milk was higher than that of outdoor herds. Indoor herd milk had lower concentrations of heptadecanoic

Table 3. Milk composition and FA profile according to herd management system.

	Indoor	Mixed	Outdoor	SEM[1]	*P*
Protein (%)	3.14[a]	3.06[b]	3.07[b]	0.008	***
Fat (%)	3.57[a]	3.46[b]	3.45[b]	0.015	**
Lactose (%)	4.76[a]	4.71[b]	4.68[b]	0.009	**
Urea (mg dl^{-1})	29.4[a]	26.9[b]	25.6[b]	0.509	**
Fatty acids (g100 g^{-1} FA)					
C6:0	3.01	2.97	2.96	0.017	NS
C8:0	1.65	1.62	1.58	0.012	NS
C10:0	3.21[a]	3.09[b]	3.01[b]	0.034	*
C11:0	0.12	0.11	0.10	0.004	NS
C12:0	3.47[a]	3.51[a]	3.20[b]	0.037	**
C13:0	0.049	0.047	0.038	0.002	NS
C14:0	10.70[a]	10.41[ab]	10.11[b]	0.075	**
C14:1	0.85	0.81	0.78	0.015	NS
C15:0	0.95[b]	1.04[a]	0.95[b]	0.013	*
C16:0	30.16[a]	27.58[c]	28.74[b]	0.214	***
C16:1	1.82[a]	1.69[b]	1.68[b]	0.020	**
C17:0	0.80[b]	0.94[a]	0.90[a]	0.021	*
C17:1	0.12[b]	0.17[a]	0.14[ab]	0.005	**
C18:0	13.36[b]	13.93[a]	13.84[a]	0.084	**
C18:1 *cis*9	24.44	25.24	25.07	0.150	NS
C18:1 *trans*11	1.81[b]	2.86[a]	2.71[a]	0.074	***
C18:2 *cis*9 *cis*12	2.59	2.45	2.68	0.048	NS
C18:2 *cis*9 *trans*11	0.47[b]	0.97[a]	0.86[a]	0.033	***
C18:2 *trans*9 *trans*12	0.07	0.08	0.09	0.003	NS
C18:3 *cis*9 *cis*12 *cis*15	0.25[b]	0.41[a]	0.42[a]	0.013	***
C18:3 *n*-6	0.013	0.011	0.011	0.001	NS
C20:0	0.05	0.06	0.05	0.002	NS
C20:2	0.010	0.005	0.000	0.002	NS
C20:4	0.08	0.05	0.09	0.007	NS
SFAs	67.56[a]	65.32[b]	65.51[b]	0.208	***
UFAs	32.43[b]	34.67[a]	34.49[a]	0.208	***
n-6 : *n*-3 ratio	11.84[a]	6.29[b]	7.17[b]	0.504	***

[a,b,c]Means in a row with unlike letters differ significantly.
*$P < 0.05$, **$P < 0.01$, ***$P < 0.001$. NS, not significant.
[1] SEM, standard error of the means.

(C17:0) and heptadecenoic (C17:1) acids and higher concentration of palmitoleic (C16:1) acid than that of the mixed or outdoor herds. In addition, the total medium-chain FA concentration of the indoor herd milk was higher (45.38 g 100 g^{-1} FA, $P \leqslant 0.001$) than that of the mixed and outdoor herd milk (42.63 and 43.26 g 100 g^{-1} FA for mixed and outdoor herds, respectively). The concentrations of oleic and linoleic acids were not affected by the management system. The indoor herd milk showed lower concentrations of stearic, vaccenic (C18:1 *trans*11), rumenic (C18:2 *cis*9 *trans*11) and linolenic acids than that of the outdoor and mixed herds. In addition, the total long-chain FA content of the indoor herd milk was lower ($P \leqslant 0.001$) than that of the mixed and outdoor herd milk (43.09, 46.00 and 45.83 g 100 g^{-1} FA, respectively).

The indoor herd milk had a higher ($P \leqslant 0.001$) content of SFA (65.52 g SFA 100 g^{-1} FA) than the mixed and outdoor herd milk (65.25 and 65.47 g SFA 100 g^{-1} FA, respectively). The SFA : UFA ratio of the indoor herd milk was significantly greater ($P \leqslant 0.001$) than that of the mixed and outdoor herd milk (2.09 versus 1.91 and 1.89, respectively). The desaturase activity of the mammary gland[17], estimated for pairs of FAs C14:1–C14:0, C16:1–C16:0 and C18:1–C18:0 was similar for all herd management systems. However, the CLA : C18:1 *trans*-11 ratio was higher ($P \leqslant 0.01$) for the outdoor and mixed (0.32) herds than for the indoor herds (0.20).

Discussion

Lower dry matter intake and milk production are typically associated with grazing relative to more intensive feeding systems[18]. Certainly, in the present work, milk yield per lactation was higher under the indoor system compared to the other systems, while FA profiles of the herds under the three management systems differed. Fresh forage fed to the mixed and outdoor herds was the main factor behind these differences. The diet of the indoor herds explains the higher short- and medium-chain FA content of their milk[8,19]. This diet could change ruminal fermentation towards propionate production because of a higher proportion of cereal feedstock[20]. Acetate and β-hydroxybutyrate are necessary for the *de novo* synthesis of FAs in the mammary gland[21]. Variations in the milk concentration of short- and medium-chain FAs have been reported, although some authors report no differences in the milk produced by herds under grazing and intensive management systems[22]. The low concentrations of palmitic and palmitoleic acids in milk for the mixed and outdoor herds might be a consequence of low energy intake or body pool mobilization[23]. However, palmitic acid concentration in milk fat seems to result from its content in the diet[20], because if body fat had been mobilized, the milk oleic acid concentration should have increased, since this FA is the most concentrated in the body reserve[24]. In this work, the oleic acid content was similar in the milk of all three herd types. Nevertheless, this hypothesis cannot be ruled out since the oleic acid in milk can also be obtained from *de novo* synthesis via the desaturation of stearic acid in the mammary gland[25].

Although grass intake was not estimated for this study, a direct relationship between daily grazing time and grass intake has been observed[8]. Therefore, it can be assumed that cows in outdoor management eat more grass than cows in mixed management. However, according to data provided by farmers in this study, the TMR intake was similar in indoor and mixed farms, which is in agreement with previous studies[26]. Therefore, elevated rumenic and vaccenic acid contents in outdoor and mixed herd milk are associated with fresh forage consumption. This confirms the results of several authors who studied the effect of grazing-based management systems on milk FA concentration[27]; although it should be noted that some authors have

not found differences in the rumenic acid concentration of milk produced by cows under indoor and outdoor systems[28].

The high proportion of unsaturated FAs, especially linolenic acid, in fresh forage would explain the increase of linolenic acid in the milk of cows feeding on grass, despite being the PUFA most susceptible to ruminal biohydrogenation[29]. Up to 99% of dietary linolenic acid intake may be totally or partially hydrogenated in the rumen, synthesizing vaccenic and stearic acids[30]. Vaccenic acid is desaturated in the mammary gland producing rumenic acid with the addition of a double bond between carbon 9 and 10[31]. The CLA : C18:1 *trans*-11 ratio serves as a marker of Δ-9 desaturase activity[32]. When fresh forage was included in the diet, this index was higher, reflecting greater desaturase activity in grazing cows. The finding of increased vaccenic and rumenic acids in the milk of the mixed and outdoor herds is consistent with that described by other authors[7]. This shows that fresh forage intake can improve the concentration of healthy FAs in milk, while feeding on high proportions of concentrates and conserved forage reduces their content.

The lower concentration of SFAs and the higher concentration of UFAs in the outdoor and mixed herd milk agree with the results of other studies in which fresh forage was included in the diet[7,8]. The SFA : UFA ratio of the indoor herd milk (2.09) was above the current dietary limit of 2.0[33], while in the outdoor and mixed herd milk it was less than 2. The *n*-3 FA concentration increased significantly in the milk of the mixed and outdoor herds, while the *n*-6 FA concentration was not affected by the management system. However, the *n*-6 : *n*-3 ratio in the mixed and outdoor herd milk was 6.7, while in the indoor herd milk possessed a ratio of 11.8, which exceeded FAO dietary recommendations regarding essential FA intake[33].

The differences in milk fat and protein concentrations between the indoor and mixed/outdoor systems were in agreement with Bargo et al.[18]. However, our results contrast with other authors, who reported lower fat and protein contents in the milk of herds fed preserved forage (maize silage, grass silage and cereal straw) and concentrates[27] or TMR[34] than in herds whose diets included fresh forage. Other authors report no differences in the fat and protein contents of the milk of cows fed TMR or grass[19]. The TMR of the present indoor herds was based on preserved forage and a high level of concentrates. This could have increased the metabolizable energy (ME) intake as well as the concentration of propionate in the rumen, and it would result in an increase in milk protein[35]. In this paper, the TMR offered in indoor farms had higher, although not significant, net energy concentration than TMR in mixed and outdoor farms. In general, the first limitation to milk protein synthesis in grazing systems is the amount of ME available since grass has an excess of degradable protein[36]. Thus, the differences in the protein concentration of the milk of the outdoor herds compared to that of the indoor herds might be due mainly to the formers' low ME and/or degradable protein intake. In this sense, increasing ME intake increases the rate of microbial protein synthesis and propionate relative to acetate in the rumen[20], resulting in increased rates of synthesis of milk protein, lactose, and to a lesser degree, fat in the mammary gland[35]. This may have occurred with indoor management.

Conclusion

Fat and protein in milk increased under the indoor feeding system, but milk FA profiles improved for both the mixed and outdoor systems. Therefore, milk from herds whose diets included fresh forage from grazing was of better quality in terms of total FA content, SFA and SFA : UFA ratio. Grazing appears to increase linolenic, vaccenic and rumenic acids in milk, while maintaining the *n*-6 : *n*-3 ratio within current nutrition recommendations.

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Salinity effects on food habits in three coastal, rural villages in Bangladesh

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Abstract

Since shrimp farming started in Bangladesh in the 1970s, it has spread throughout the coastal region, increasing soil and water salinity levels. The water salinity in 2005 in the coastal districts of Khulna, Bagherat and Satkhira ranged from 0.3 to 20.7, 0.4 to 27.1 and 0.7 to 24.8 dS m^{-1}, respectively, whereby it was highly saline for several months of the year. Water salinity above 2.5 dS m^{-1} is not suitable for irrigation, and may cause animal health problems. Irrigation with saline water may cause ion toxicity and osmotic stress, reducing plant growth and yield. Salinity has reduced the agro-biodiversity in the coastal regions of Bangladesh, and this paper investigates how these changes have impacted human food habits in the three coastal, rural villages Putia (Satkhira district), Srifaltala (Bagerhat district) and Hogolbunia (Khulna district). Fieldwork was conducted from July to December 2006 and Participatory Rural Appraisal methods including transect walks, key informant interviews, group discussions and personal interviews were carried out. In total, 121 respondents were interviewed and historical data from 1975 to 2006 were collected. For historical data, respondents aged above 50 years were sampled, but additional criteria such as socio-economic condition and farm location were applied to assure a sample representative for the population of the coastal areas. The sampled households had characteristics similar to the major part of Bangladeshi households (rural, agrarian based, regarding family size and food habits), and were thus representative of a broader cross-section of households in Bangladesh. As all sampled villages faced increasing salinity and spread of shrimp farming, they were representative of villages in the coastal areas. When salinity increased, the production of vegetables, seasonal fruits, animal species, eggs and milk declined. As the price of the mentioned animal commodities rose, cheaper commodities such as broilers, exotic and marine fish species and exotic oils were introduced. The decision on what to cultivate was also influenced by non-residents converting the farmers' land into shrimp ponds, increasing the salinity in the surroundings and killing the farmers' ducks. These agro-biodiversity changes caused reduced frequency of consumption of beef, goat, native chicken, egg, local freshwater fish, seasonal fruits, vegetables and milk, while broilers, exotic fish, exotic oils and marine fish species were increasingly consumed. Still, the total fish consumption declined. These changed food habits may lead to considerable negative health consequences for the rural, coastal populations.

Key words: agro-biodiversity change, Bangladesh, coastal area, food habits, salinity, shrimp aquaculture

Introduction

Food is being used to satisfy hunger and meet nutritional needs, it is also used as a gift and to show hospitality in order to create and maintain social relations. Food can denote ethnic, regional and national identity and it is an important part of holidays, celebrations and special family occasions.[1,2]. Foods have symbolic meanings in religious rituals and beliefs and can be used to show status, make one feel secure, express feelings and emotions, to relieve tension, stress or boredom[1,2]. Cultural values influence how people use food and eating cultures, varying among regions and within societies, are influenced by class, age and gender[3]. The developed attitude toward food evolves from learned experiences, often influenced by cultures and traditional practices, and food is used for self-expression

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and/or showing group membership[4,5]. Food habits may be described as 'the culturally standardized set of behaviors in regard to food manifested by individuals who have been reared within a given cultural tradition,[6,21] and food habits are continually changing as they adapt to travel, immigration and the socioeconomic environment[1,2,7,8]. Food preferences indicate the amount of satisfaction an individual anticipates from eating food[9]. Preferences are a factor of physiological and psychological development as well as social experiences, and are related to the degree of liking food. Liked foods are familiar, considered pleasant and more frequently eaten, while disliked foods are rejected as they are considered unpleasant or unfamiliar. Taste is considered the most important sensory attribute to food selection, but texture, color, shape, form, size of pieces and temperature are also important factors[9]. While familiarity is one of the most important factors of child and adult preferences[10–12], the liking for bitter or strong-tasting foods increases with the age[13]. Also, socioeconomic environment influences culture and food habits[1,7,8].

In Bangladesh, rice is the staple food and is often consumed thrice daily. Traditionally, it was common to raise cattle, chicken, ducks and goats for meat and milk, and to grow vegetables as well as plants for oil extraction in the homesteads. The majority of the rural households owned cattle, had income from selling calves, milk and cow dung for fuel, and animals were available for sacrifice in holy festivals[14]. Poultry were kept by many families and women had supplementary income from selling chickens and eggs[14]. Rural households used to cultivate vegetables and sell the surplus after meeting household needs[15]. Shrimp farming, which started in Bangladesh in the 1970s, has spread to many coastal districts[16,17], and although it is important for the national economy[18,19], it has made the environment in the shrimp-producing areas increasingly saline[20]. The Bangladeshi coastal area has great potential for agricultural development, but salinity is the main limiting factor[21]. Salinity is divided into the following categories: non-saline (0–1.9 dS m^{-1}), slightly saline (2–4 dS m^{-1}), moderately saline (4.1–8 dS m^{-1}), saline (8.8–16 dS m^{-1}) and highly saline (>16 dS m^{-1})[22]. Soil and water salinity in Bangladesh varies throughout the year and is generally high in the dry season, January to July, and lower during the heavy rainfall, August to December[23]. The yearly average soil salinity in the coastal sub-districts Batiaghata and Rampal increased from 1.4 to 6.9 dS $m^{-1}$and from 3.7 to 8.8 dS m^{-1}, respectively, from 1990 to 2005. In the same period, the average yearly water salinity in Kazibachha River in Batiaghata and Rampal River in Rampal increased from 2.7 to 7.6 dS m^{-1} and from 4.5 to 8.7 dS m^{-1}, respectively. The average yearly water salinity in Kakshiali River in Kaliganj increased from 9.2 to 10 dS m^{-1} from 1995 to 2005[23]. Water with electrical conductivity (EC) above 2.5 dS m^{-1} is not suitable for irrigation[24] as it may cause ion toxicity and osmotic stress, reducing plant growth and yield[25]. Poultry and pigs should not drink water with EC above 6 dS m^{-1}, as even salinity above 2.5 dS m^{-1} may cause health problems for animals and EC above 4 dS m^{-1} may cause shell cracking in laying hens[26]. Although beef cattle are able to drink water up to 17 dS m^{-1}, even lower EC levels may contain unacceptable concentrations of particular ions[24]. Increased salinity has caused agro-biodiversity changes such as reductions in cattle, buffalo, goats, ducks and chickens[27–29] and rice production as well as crop extinctions and a shift from native to high-yielding varieties[26,30–32]. The species diversity and production of certain vegetables have declined and half of the 32 crop species grown in Satkhira in 1985 were extinct by 2000 due to salinity[15,30,33]. Farmers in shrimp-producing, coastal areas used to grow pulses, oil seeds and vegetables, but now there are no longer any winter crops[34,35]. Salinity has caused a reduction in fruit trees[28,29,36,37] and while indigenous fish varieties disappear, exotic and marine species become dominant[38].

With declining yields and disappearance of species, the rising food prices[39] may further reduce the availability of food and have negative effects on the nutritional status and health of vulnerable populations[40]. In Bangladesh, nearly half of the population is poor[41] and food insecure, and use coping strategies such as starving 1–2 times a day (54%) and reducing the intake of favorite foods (49%)[42]. Nationally, a high proportion of children under 5 years are underweight and stunted (40 and 46% respectively), a scenario similar for Khulna (35 and 44%) and Chittagong division (40 and 52%)[43]. Consumption of seeds and legumes, yellow and orange fruits, vegetables, root crops and green leafy vegetables can prevent micronutrient malnutrition[44], and thus a diverse diet is essential to ensure the intake of the 17 minerals and 15 vitamins needed for good health[45]. However, the Bangladeshi average daily intake of vegetables and fruits is 179.5 g[46], which is far below the World Health Organization recommendation of 400 g[47]. The Bangladeshi government and NGOs have thus launched large-scale food and nutrition programs, including direct food and nutrient supply, school feeding, home gardening and health advice, to combat and prevent nutrient deficits[48,49]. For advice to have any impact, it is important to know which factors influence the people's food habits and food choices[50]. The salinity increase in the Bangladeshi coastal areas has degraded the environment and caused a decline in agro-biodiversity, with various species lost. This research examines how the salinity-induced changes in agro-biodiversity (here crops, fruit trees and livestock) have affected the people's food habits in the villages Putia, Srifaltala and Hogolbunia in the coastal area of Bangladesh.

Materials and Methods

The three villages in this study, Putia in Kaliganj sub-district of Satkhira district, Srifaltala in Rampal sub-district of Bagerhat district and Hogolbunia in Batiaghata sub-district of Khulna district in Khulna division in Bangladesh, were selected based on their farming systems and salinity

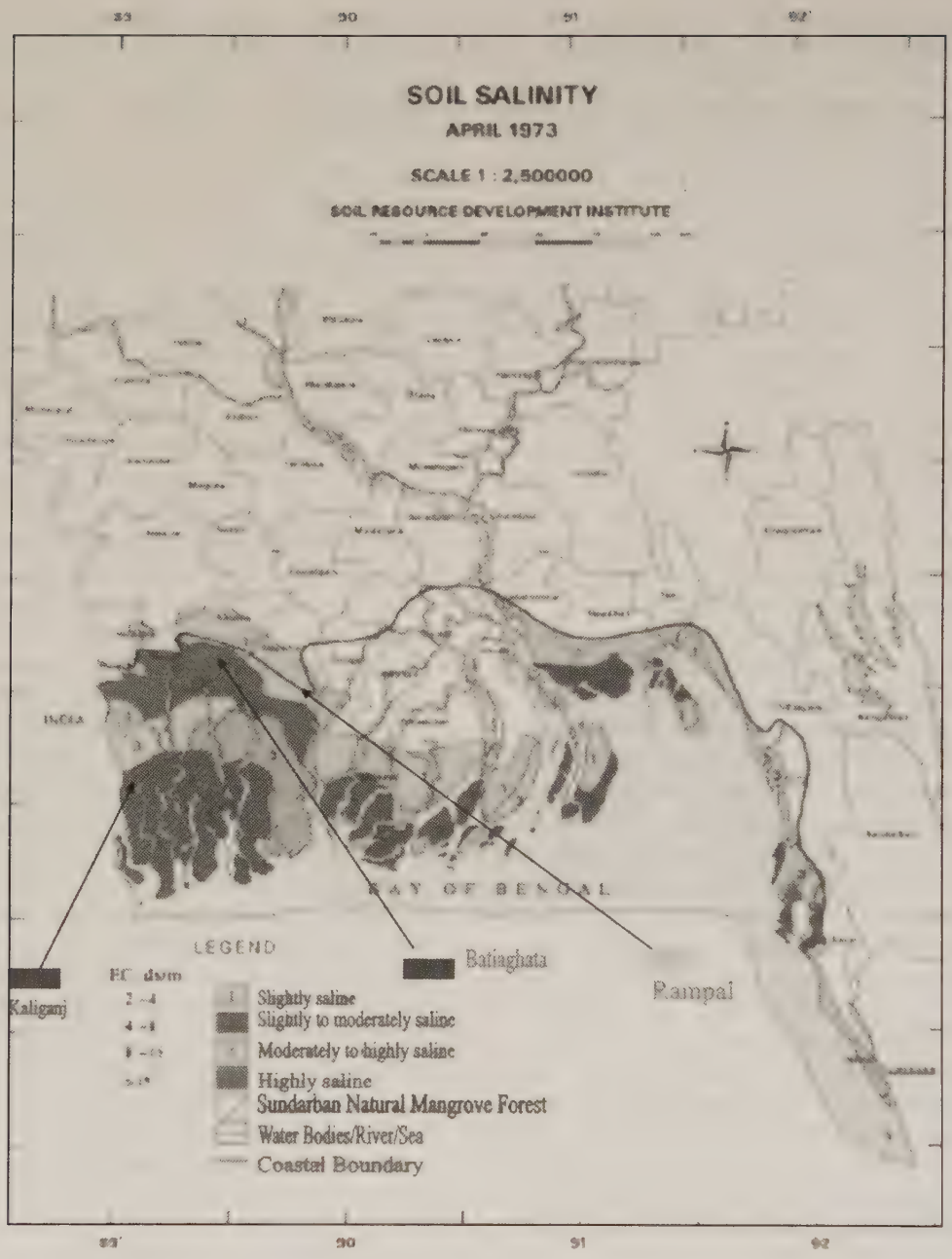

Figure 1. Salinity-affected areas in Bangladesh, 1973, including study areas.

levels (Figs. 1 and 2). Participatory rural appraisal (PRA) was used to assure wide participation of the communities and obtain more accurate data[51]. The PRA tools included transect walks, personal interviews with farmers, focus group discussions and key informant interviews. To obtain preliminary information about the study sites, salinity, livelihood, cropping pattern and food habits, each study area was visited for 10 days in July and data collected from local teachers, experienced farmers and officers of sub-district Agriculture, Fisheries and Livestock. Additional information on cultivated species was collected from five teachers at Khulna University (specialized in agriculture, forestry, soil science and fisheries) who had grown up in the study areas. A transect walk was done in each study area to cross-check information and the questionnaires were pre-tested on local farmers.

For personal interviews, a sample of 34 farmers in Putia, 43 in Hogolbunia and 44 in Srifaltala were selected. The sample sizes, based on the number of agricultural households in the sampled villages, were calculated with 95% confidence ($z = 1.96$) and 10% error margin ($e = 0.1$) by the following equation[52]:

$$n_o = z^2 p\ (1-p)/e^2, \tag{1}$$

where n_o is the sample size not corrected with the finite household correction factor, z is the level of confidence, p is

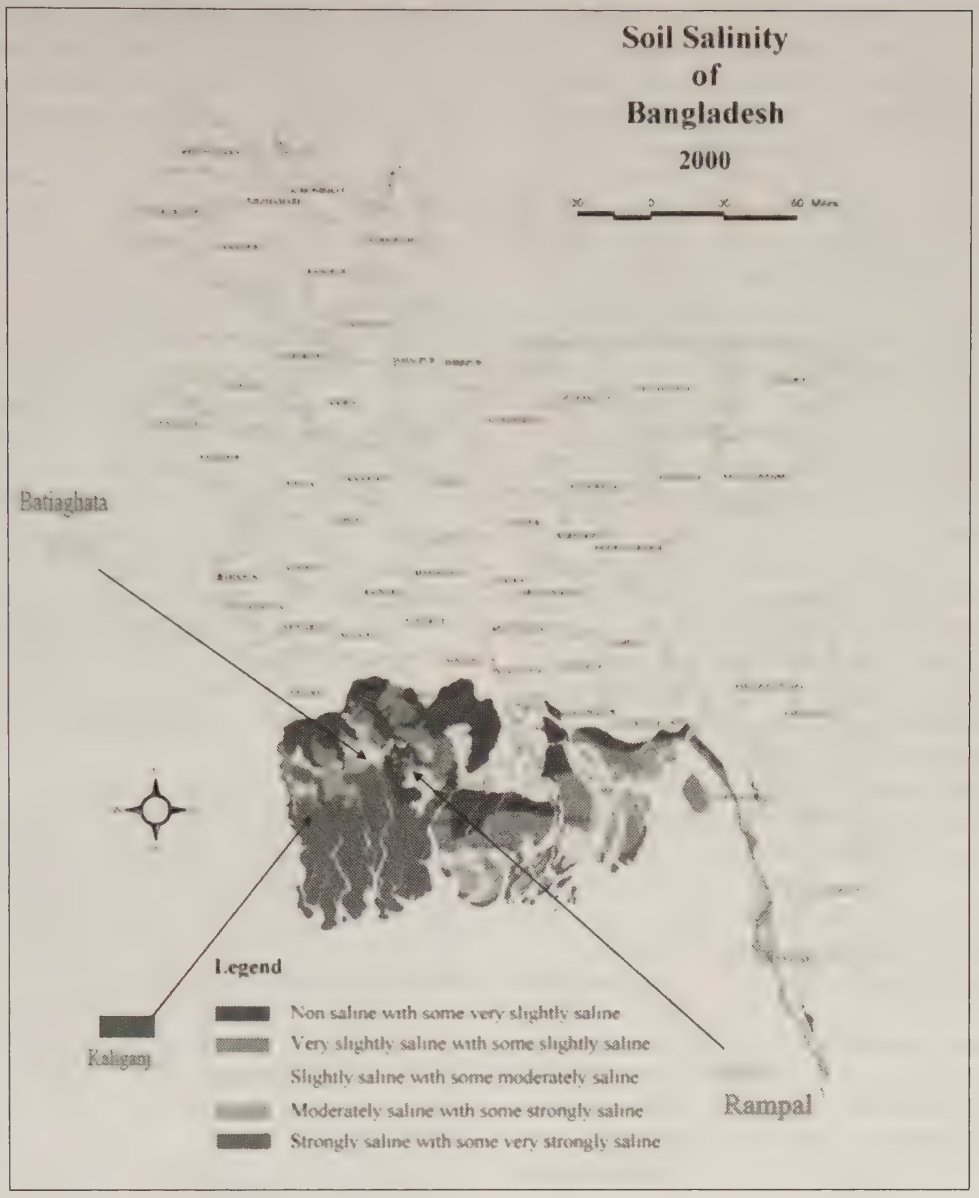

Figure 2. Salinity-affected areas in Bangladesh, 2000, including study areas.

the proportion of the households and e is the accepted sampling error.

Then the finite correction factor was applied to correct the calculated sample size[52]:

$$n = n_o N/(n_o + (N-1)), \quad (2)$$

where n is the sample size considering the finite household correction factor and N is the total number of households in the study area.

To obtain historical data from 1975 to 2006, purposive sampling was used to select respondents aged above 50 years, who had been living and engaged in farming in the area since 1975. To assure a representative sample and capture diverse views, additional selection criteria were socioeconomic condition and farm location. All respondents for the personal interviews were men. As Bangladeshi women move to their husbands' home area upon marriage, the women in the study areas could not provide historical data for that area, so to capture the women's views they were instead sampled for group discussions. All personal interviews were conducted individually in the respondents' homes, enabling observation and data verification. Semi-structured questionnaires covering the topics, cropping practices, livelihood, food habits in 1975, 1990 and 2006, and reasons for change in food habits, were used. A checklist covering livelihood situation and challenges; environment, cropping patterns and species cultivated in 1975, 1990 and 2006; perception of salinity levels; salinity effects and management; main income sources; comparison between rice and shrimp cultivation and conflicts due to shrimp farming was used for the key informant interviews and group discussions. In each study area, key informant interviews with 18 local people, including six experienced farmers, 10 school teachers, four officers of the sub-district

Forestry, Agriculture, Fisheries and Livestock, the local leader and one imam were conducted. Six group discussions, separately for men and women, were conducted in each study area, including two mixed group discussions with 10 young and 10 elderly farmers, two with 10 elderly farmers (above 40 years) and two with 10 young farmers (20–40 years) to avoid influence from one age group on the other and cross-check information. In Hogolbunia and Srifaltala, the key informants and group discussion participants were different from the personal interview sample. However, in Putia, the entire population of elderly farmers was sampled for personal interviews, and so key informants and elderly farmers in the group discussions were the same as those for personal interviews.

The respondents perceived that the salinization in their areas started in 1975 and shrimp cultivation in 1990. The selected base year for comparison of change in salinity was thus 1975. As 15 years is considered to be a sufficiently long time interval to observe substantial changes in environmental parameters, 1990 and 2006 were selected to obtain information about the salinity-induced changes. As 1975 was close to the year of independence (1971) and there was a conflict between the people of Bangladesh and the military government in 1990, both years are thus memorable for the respondents and made it easier for them to remember historical data. Data from the individual interviews were analyzed by Excel.

Description of Respondents and Study Areas

The entire coastal area in Bangladesh, which comprises the divisions of Chittagong and Khulna, is affected by salinity (Figs. 1 and 2). This salinity increase is partly caused by shrimp farming, which has spread throughout the coastal region[53], reduced rice production and limited livestock and poultry rearing[53]. Shrimp cultivation covered 33% of the total land in Bagerhat, 19% in Satkhira and 24% in Khulna in 1994[54], and from 1975 to 1999, the area under rice production in Rampal decreased from 80% to less than 20%[55]. Of the 156 million people in Bangladesh, 38.5 million live in the coastal areas and 14.5 million live in Khulna division. The majority of the households in Bangladesh (88%) as well as in the coastal areas (91 and 88% in Khulna and Chittagong, respectively), are rural based and engaged in agriculture (64, 56 and 57% in Khulna, Chittagong and nationally, respectively). For about a third of the households in Bangladesh (38, 27 and 31% in Khulna, Chittagong and nationally, respectively), agriculture is the main income source[56]. The population of the study areas was 3000, 6116 and 2700 in Hogolbunia, Srifaltala and Putia, respectively. All the respondents were farmers born in the study areas, with mean ages from 61 to 63, and the average family sizes (5.8, 5.2 and 5.4 in Hogolbunia, Srifaltala and Putia, respectively) were similar to the national average (5.8)[57]. In Hogolbunia, the majority of the respondents (60%) were subsistence farmers, 35% also had small-scale commercial rice production and 5% got their main income from teaching or shrimp production. The majority of the respondents in Hogolbunia (70%) were only sharecropping; some (21%) owned land in addition to sharecropping and very few (9%) only cultivated their own land. In addition, all rented public land close to the river for small-scale, non-intensive shrimp production. In Srifaltala, all respondents cultivated rice intensively, commercially. A proportion of 95% had additional, intensive, commercial shrimp production, whereas 5% were day laborers and teachers. All the respondents in Srifaltala owned land and only 5% rented additional land. All the respondents in Putia had intensive, commercial shrimp and rice production, 21% also had small businesses and the rest worked as teachers, laborers, doctors and cycle/van drivers in addition to the farming. The respondents' average years of education (four in Hogolbunia and Srifaltala and six in Putia) was lower than the national average of eight[43]. In Srifaltala and Putia, the majority of the respondents (93 and 82%, respectively) were Muslim and the rest were Hindu, values that are close to the national proportions (90% Muslim and the rest mainly Hindu)[57]. In Hogolbunia, all the respondents were Hindu.

The main source of income in the study area was from shrimp cultivation related livelihood activities based on wild shrimp larvae from the rivers. The shrimp farms were mainly surrounded by low earthen dikes with small wooden sluices, which were opened from February to April to allow the entry of saline water with post-larvae shrimp and fish. In June/July, when the water in the shrimp pond reduced, the majority of the shrimps and fish were harvested and rice was planted. In Putia, which had the highest salinity level of the three villages (>15 dS m^{-1} from March to July), the water salinity in the shrimp farms and Putia river was so high that it was used to produce salt. In Srifaltala, the salinity was high (8.1–16 dS m^{-1} from March to May), but it was even higher at the sub-district level (14–25 dS m^{-1}). Farmers in Putia and Srifaltala cultivated shrimp and fish intensively in large farms, and in Putia they added extra salt to their shrimp/fish ponds to increase the salinity. Most of those farmers cultivate rice in separate fields allocated close to the shrimp farms. While it was common to have an additional field only for rice in Putia, this was not common in Srifaltala. Although Hogolbunia had the lowest salinity level (2–4 dS m^{-1} from March to April) of the three villages, the salinity at the sub-district level (15–17 dS m^{-1}) was higher than in Hogulbunia village[23]. In Hogulbunia, some rice was grown together with the shrimp, and in addition there were separate fields for intensive rice cultivation. Large barriers were erected between the shrimp pond and the rice field to prevent river water from entering the fields. In all three villages, farmers grew vegetables in elevated land in their homestead close to the shrimp farm, and irrigated with brackish well water. Homestead production is common throughout Bangladesh[58], and the large species variety is vital for the livelihoods[59,60]. Despite the

Table 1. Changes in the consumption of goat and beef meat in the study areas. P, Putia; S, Srifaltala; H, Hogolbunia.

	Goat meat									Beef					
	1975			1990			2006			1975		1990		2006	
Days/ month	P	S	H	P	S	H	P	S	H	P	S	P	S	P	S
	Respondents (%)														
0	12	2	0	15	7	2	88	80	81	15	11	15	11	77	20
1–5	65	9	98	82	55	95	12	20	16	62	60	71	64	21	20
6–10	24	50	0	3	36	0	0	0	3	24	13	15	18	0	51
11–15	0	32	2	0	2	2	0	0	0	0	9	0	7	0	7
16–20	0	5	0	0	0	0	0	0	0	0	4	0	0	0	2
21–25	0	2	0	0	0	0	0	0	0	0	2	0	0	0	0
26–29	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
30	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

common practice of cultivating homesteads on elevated land, salinity still reduces the production[59,60].

Results and Discussion

Food habits

All the respondents' food habits had changed from 1975 to 2006 due to salinity increase, shrimp farming, introduction of new foods and increased income and population. Despite changing food habits, the respondents cultivated rice as the staple food and continued eating it thrice daily, as they felt a meal was incomplete without rice. The concept and daily number of meals are among the most difficult aspects of food habits to change[50], and as rice is among the cheapest sources of calories in Bangladesh, rural people first satisfy their need for rice and only buy vegetables, meat and fish with the remaining money[61]. As rice is a staple food, the increasing machine polishing, removing the protein-rich outer layer, is alarming[62]. Bangladeshi consumers prefer the non-sticky and small-grain rice varieties, without regarding the nutritive value[62]. Gender also impacts the food preferences and habits, as in the Biodiversity Use and Conservation in Asia (BUCAP) conservation project of local rice varieties where women emphasized on aroma and good eating quality while men preferred high yields[63].

Beef and goat meat

In 1975, beef was the most consumed meat in Putia and Srifaltala, eaten on average 4 and 6 days per month, respectively (Table 1). From 1990 to 2006, the proportion of respondents who did not eat any beef monthly increased from 15 to 77% in Putia and from 11 to 20% in Srifaltala. The people still consuming beef ate it when visiting rich relatives or attending ceremonies. When grazing land was converted into shrimp ponds, shortage of fodder for cattle arose and led many farmers to sell off their cattle. In addition, salinity-induced diseases made cattle rearing and beef meat expensive. As the farmers in Srifaltala cultivated their own land, they could afford to buy beef and were thus not so much affected by the shortage of cattle as in the other study areas. In Putia, the farmers did not cultivate their own land due to insecurity and lack of capital. They preferred to lease their land instead of risking that the owners of the large shrimp farms would take it by force. The farmers only received about US$60 per 2000 m^2 per year and thus could not afford to buy beef. Most people in Hogolbunia had cattle, but did not eat beef for religious reasons.

The frequency of eating goat meat declined from an average of 4 (Putia and Hogolbunia) and 11 days per month (Srifaltala) in 1975 to 1 day per month in all the study areas in 2006 (Table 1). In the same period, the proportion of respondents who did not eat goat meat monthly increased from none to 81% in Hogolbunia, from 2 to 80% in Srifaltala and from 12 to 88% in Putia. The reasons for this decrease were salinity-induced unavailability of goat meat and related high prices, as explained by a farmer in Hogolbunia: 'We used to eat goat until 1990, but now people prefer the cheaper broiler and pork. People have goats, but due to high prices they rather sell it. In 1975 people had goat meat in every ceremony, but now goat meat is rare in parties. People also eat less goat meat due to larger family size and joint families. In 1975, one kilo goat meat was sufficient for three meals, but now two kilos are not sufficient for one meal'.

In Bangladesh, farmers use rice straw, hay, bran and husks as livestock fodder, but increased salinity has reduced rice cultivation and thus also livestock production[31,64]. Also flooding, which has reduced the available grazing land and fodder[64–66], and salinization of water have caused increased livestock mortality[14]. Consequently, salinity-induced cattle diseases have led farmers in Putia and Srifaltala to sell off their cattle[27]. The total cattle production in Bangladesh has decreased[21], especially in the shrimp farming areas, where the number of households keeping cattle yearly reduced by 9% from 1990 to 1995[29,55,67–69], and many sold their cattle to invest in shrimp aquaculture[17,66]. The reduction in grazing land has

Table 2. Changes in the consumption of milk and egg in the study areas. P, Putia; S, Srifaltala; H, Hogolbunia.

	Egg									Milk								
	1975			1990			2006			1975			1990			2006		
Days/month	**P**	**S**	**H**	**P**	**S**	**H**	**P**	**S**	**H**	**P**	**S**	**H**	**P**	**S**	**H**	**P**	**S**	**H**
	Respondents (%)																	
0	0	0	0	0	7	0	6	41	0	3	0	0	3	0	0	74	91	94
1–5	9	2	0	9	11	0	71	45	23	3	2	0	3	2	0	15	7	5
6–10	3	9	0	18	16	40	15	14	74	0	0	0	0	5	0	6	2	0
11–15	15	25	23	32	21	42	3	0	2	0	0	0	0	2	0	0	0	0
16–20	21	32	72	27	30	16	6	0	0	6	0	2	15	2	12	3	0	2
21–25	21	9	2	9	5	2	0	0	0	3	0	14	3	0	7	0	0	0
26–29	0	2	0	0	0	0	0	0	0	0	0	2	0	0	2	0	0	0
30	32	21	2	6	11	0	0	0	0	85	98	81	77	89	79	3	0	0

caused a decline in the number of goats[55]. Deb[64] confirms that if local peasants in the coastal areas refuse to lease their land to the socially and politically powerful and wealthy shrimp farm owners, the latter inundate the land with brackish water, increasing saline water intrusion into nearby paddy fields. The subsequent losses in rice production force the peasants to lease their land to the shrimp farm owners on the latter's conditions[64].

Milk

The respondents liked milk, but monthly average consumption declined from 27 (Putia) and 29 days per month (Hogolbunia and Srifaltala) (Table 2) in 1975 to 2 (Putia) and 1 (Hogolbunia and Srifaltala) in 2006. According to nearly all the respondents (93, 91 and 74% in Hogolbunia, Srifaltala and Putia, respectively), the reason was unavailability of cattle, as described by a farmer in Srifaltala: 'In 1975 the average household had seven, eight cows and people drank milk twice or thrice daily. Due to shrimp farming there is shortage of grazing land and fodder, and fewer cattle. People have money, but as milk is not available, only rich people with cattle farms, still drink it'. Shortage of milk and cattle in the coastal areas is also documented in other studies[19]. As reduced intake of milk, which is rich in vitamin A, may cause nutrient deficiencies[19,44], the reduced cattle-raising in Bangladesh has had serious economic and nutritional consequences[34,35], especially for the children[14,15,70].

Native chicken, egg and broilers

All the study areas experienced a decline in the consumption of native chicken from 1975 to 2006 (Tables 3 and 4). From 1990 to 2006 the proportion of respondents not eating native chicken monthly increased from 6 to 82% in Putia and from 11 to 84% in Srifaltala. While all respondents in Hogolbunia still raised native chicken, very few in Srifaltala and Putia did. Some farmers in Putia and Srifaltala still reared duck after 1990, but many stopped as the shrimp owners killed the ducks because they ate the shrimp larvae. The high salinity levels in Putia and Srifaltala caused poultry diseases, watery droppings and high mortality, making native chicken rearing difficult. According to the respondents, the native chicken did not catch diseases so frequently prior to the introduction of shrimp farming. From 1975 to 2006 all study areas experienced a large decline in the consumption of eggs, which dropped from an average of 23 (Putia) and 20 (Srifaltala and Hogolbunia) days per month to 3 days per month in Putia, 1 in Srifaltala and 11 in Hogolbunia (Table 3). Salinity-induced stomach diseases, mortality and reduced growth rate and consumption of chicken is widely documented[36,55,58,71,72]. About 80% of the households in shrimp farming areas of Khulna and Satkhira faced large declines in poultry production[21,68], and the number of native chicken in Dacope, near Hogolbunia, decreased by 90% from 1995 to 2001 due to salinity-induced diseases and drinking water scarcity[69]. Large declines in the number of ducks in Srifaltala[55] and the shrimp farmers' practice of banning ducks[14,15,55] have also been documented elsewhere.

Commercial broiler production was introduced to the rural areas of Bangladesh in 1990[26], and in 2006 the respondents ate broiler on average 4 (Putia), 5 (Hogolbunia) and 8 (Srifaltala) days per month (Table 3). Most of the respondents preferred the cheap broiler to the expensive and unavailable native chicken. In Hogolbunia, the increased broiler consumption was due to lack of alternative meat sources, as goat and native chicken were expensive and beef was not consumed. A farmer in Putia said: 'People prefer to rear broiler rather than native chicken due to profits and because native chicken catch diseases when they go to the shrimp farms, drink saline water and eat harmful waste material, while broilers are reared in protected rooms.' However, the average days per month consuming poultry were stable or increased in the study areas.

Table 3. Change in the respondents' consumption of certain foods.

	Putia			Srifaltala			Hogolbunia		
	Mean days of consumption per month								
	1975–1990	1990–2006	1975–2006	1975–1990	1990–2006	1975–2006	1975–1990	1990–2006	1975–2006
Beef	-1^{1}	-3^{1}	-4^{1}	-1^{ns}	$+2^{10}$	$+1^{ns}$	No	No	No
Goat	-1^{1}	-2^{1}	-3^{1}	-6^{1}	-5^{1}	-11^{1}	-2^{1}	-2^{1}	-4^{1}
Native chicken	-1^{1}	-2^{1}	-3^{1}	-4^{1}	-4^{1}	-8^{1}	-6^{1}	-5^{1}	-11^{1}
Milk	-1^{10}	-24^{1}	-25^{1}	-2^{ns}	-27^{1}	-29^{1}	-1^{ns}	-28^{1}	-29^{1}
Egg	-6^{1}	-12^{1}	-18^{1}	-4^{1}	-13^{1}	-17^{1}	-5^{1}	-6^{1}	-11^{1}
Fresh water fish	-3^{1}	-21^{1}	-25^{1}	-0.4^{ns}	-29^{1}	-29^{1}	-21^{1}	-18^{1}	-21^{1}
Marine fish	$+0.4^{5}$	$+17^{1}$	$+17^{1}$	$+6^{1}$	$+19^{1}$	$+24^{1}$	$+7^{1}$	$+13^{1}$	$+20^{1}$
Native oil	0^{ns}	-30^{1}	-30^{1}	-1^{ns}	V30^{1}	-30^{1}	-1^{ns}	-30^{1}	-29^{1}
Seasonal fruits	-3^{1}	-6^{1}	-10^{1}	-4^{1}	-14^{1}	-18^{1}	-6^{1}	-8^{1}	-14^{1}
Winter vegetables	-3^{1}	-13^{1}	-16^{1}	-3^{1}	-10^{1}	-13^{1}	-6^{1}	-6^{1}	-11^{1}
Summer vegetables	-4^{1}	-12^{1}	-17^{1}	-1^{1}	-3^{1}	-4^{1}	-5^{1}	-5^{1}	-10^{1}

1 = significant at 1%, 5 = significant at 5%, 10 = significant at 10%, ns = not significant, No = respondents do not consume beef.
− = reduced consumption, + = increased consumption.

Fish

Fish, a staple food in Bangladesh, is consumed by literally all people, and from 1975 to 1990 the respondents mainly depended on freshwater fish, but prices increased after the introduction of shrimp cultivation and exotic fish species. Due to larger family sizes, people could no longer afford freshwater fish and the monthly average days of eating local freshwater fish dropped significantly (Table 4) from 26 to 1 in Putia and Hogolbunia from 1975 to 2006. In 2006, the majority of respondents in Putia (88%), Srifaltala (86%) and Hogolbunia (81%) did not eat freshwater fish monthly. A farmer in Srifaltala explained: 'As local freshwater fish was abundant in 1975, people ate it thrice daily, but now people mainly produce exotic fish due to high growth rates. Shrimp farming and increased salinity have made freshwater fish rare and increased their value so only rich people can afford it. Thus if people catch freshwater fish they rather sell than eat them'. While the average monthly intake of marine fish in 1975 was close to zero in all study areas, it increased by 13, 17 and 19 days in Hogolbunia, Putia and Srifaltala, respectively, from 1990 to 2006. Exotic fish species were introduced in the study areas in 1990, before that none of the respondents ate exotic fish, but in 2006 they were consumed on average 8 (Srifaltala) and 15 (Hogolbunia and Putia) days per month.

The salinity-induced decrease in indigenous and increase in marine and exotic fish species in the coastal areas[73], partly explains the respondents' shift in food habits regarding fish. However, the total fish consumption in the study areas had declined. Fish is the major source of animal protein in Bangladesh, contributing to about 60% of per capita intake[19], and although animals and fish contribute small proportions of total iron intake (4–8%), their high bioavailability contribute to better iron uptake than that from plants[61]. Small fish species are key suppliers of crucial nutrients, such as calcium, minerals, fatty acids, vitamins[74], phosphorus, iron and zinc[75], and vitamin A, especially, from these species is important for children and lactating mothers to avoid child blindness and reduce infant mortality[75]. Thus, the decrease in consumption of small fish species is serious[74], especially considering that the current annual per capita fish consumption is 4 kg below the recommended minimum (18 kg year^{-1})[41]. The sharp decrease (90%) in natural fish catch the last 20 years[76] together with fish's increased market value[77], reduces poor people's protein availability[31], with possible serious nutritional impacts[74].

Native and exotic oils

In all the study areas, people used native oils from sesame, linseed, mustard and coconut for cooking from 1975 to 1990 (Table 3). In Hogolbunia, people were self-sufficient with sesame in 1975, but saline soil and water logging decreased the yield to the extent that most had stopped cultivating it by year 2000, as explained by a farmer: 'Sesame and mustard oil were used for cooking before 1990, and although soy and palm oil were available, people preferred the sesame oil they produced. Now, water logging and salinity make sesame and mustard cultivation nearly impossible'. The native oils, used daily by nearly all respondents in 1975, increased in price partly due to salinity-induced production decrease. In 2006, native oils had been substituted by cheaper exotic oils, i.e. soybean, which were consumed on average 29 (Putia) and 30 (Hogolbunia and Srifaltala) days per month.

Vegetables and seasonal fruits

From 1990 to 2006, the average monthly consumption of winter vegetables in Hogolbunia, Srifaltala and Putia declined by 6, 10 and 13 days, respectively, and by 5, 3 and 12 days, respectively, for summer vegetables (Tables 5

Table 4. Change in consumption of native chicken and broiler in the study areas.

	Native chicken									Broiler								
	1975			1990			2006			1975			1990			2006		
Days/ month	P	S	H	P	S	H	P	S	H	P	S	H	P	S	H	P	S	H
	Respondents (%)																	
0	3	0	0	6	0	2	82	84	2	100	100	100	100	100	100	3	0	0
1–5	91	39	0	94	0	95	18	16	58	0	0	0	0	0	0	85	16	5
6–10	6	41	0	0	4	0	0	0	40	0	0	0	0	0	0	12	66	5
11–15	0	16	74	0	19	2	0	0	0	0	0	0	0	0	0	0	18	84
16–20	0	5	26	0	0	0	0	0	0	0	0	0	0	0	0	0	0	7
21–25	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
26–29	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
30	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

Table 5. Change in consumption of vegetables in the study areas.

	Summer vegetables									Winter vegetables								
	1975			1990			2006			1975			1990			2006		
Days/ month	P	S	H	P	S	H	P	S	H	P	S	H	P	S	H	P	S	H
	Respondents (%)																	
0	0	7	0	0	7	0	9	11	2	0	0	0	0	0	0	0	0	2
1–5	6	7	0	15	7	5	44	16	28	3	2	0	9	2	5	34	0	35
6–10	3	30	7	15	39	40	29	50	65	3	2	7	15	14	47	36	2	60
11–15	18	36	37	15	43	40	15	18	5	18	11	42	9	20	30	11	0	2
16–20	12	20	47	9	5	16	3	5	0	12	21	37	12	21	16	5	0	0
21–25	15	0	7	15	0	0	0	0	0	12	11	7	26	5	0	2	0	0
26–29	0	0	0	0	0	0	0	0	0	6	0	0	0	0	0	0	0	0
30	47	0	2	32	0	0	0	0	0	47	52	7	29	39	2	11	98	0

and 3). The respondents in Srifaltala did not grow many winter vegetables, but bought them. According to a farmer in Putia: 'People used to cultivate vegetables commercially, but crop failures due to increased salinity and lack of freshwater for irrigation made most farmers stop commercial winter vegetable production'. Fruit trees were abundant in the study areas in 1975, but most were salt sensitive. From 1975 to 2006, the frequency of eating seasonal fruits declined by 10, 14 and 18 days in Putia, Srifaltala and Hogolbunia, respectively, and in 2006, 21% of the respondents in Putia and 37% in Srifaltala did not eat seasonal fruits monthly. As explained by a farmer in Srifaltala: 'People ate seasonal fruits daily around 1971, but now most people do not as the fruit trees' yield and quality is very low due to shrimp farming'.

Rural people in Bangladesh get 90% of their vitamin A from vegetables and fruits[78] and 50% of their iron from non-staple plants[61], thus the decreasing consumption of these commodities is alarming. Vitamin A deficiency is a public health problem, and the coverage of the government-distributed capsules to vulnerable people is not complete[16]. Thus, home gardening has been promoted[16], and this has lowered the incidences of child blindness[79]. While a home garden project in Bangladesh demonstrated a positive relation between participants' increased knowledge about vegetables' nutritional value and their vegetable production[80], people have to be made aware about their own consumption to consider health promotion messages personally relevant[81]. Thus, lack of nutrition knowledge maybe an additional reason for the respondents' declining fruit and vegetable consumption, and also cultural preferences and habits, such as palatability, cooking properties, food storage and preparation methods, influence people's choices of food plants[82].

From 1991 to 2000, Bangladesh's food production and the national average food intake increased, but the diet of the rural and urban poor did not improve. The urban population's demand for high-protein items draws produce to the market where animal products are too expensive for the poor. Thus, the diet of the poor is becoming less diverse, with less fish, meat, fruits and vegetables, and increasingly rice-dominated. Farmers, who were once

self-sufficient in most commodities are becoming increasingly dependent on the market, and people in rural areas currently only produce 25% of what they consume[83]. The typical, rural, Bangladeshi diet is not well balanced as it mainly comprises rice (62%), some vegetables and pulses and less than 10% is protein and micronutrient-rich foods such as fish, egg, meat, milk, fats and oils[84]. Meat and milk are only consumed occasionally and in very small amounts, fish only when available and the consumption of fruits and vegetables is declining[84]. Thus, the respondents' changing food habits in Srifaltala, Putia and Hogolbunia, as well as the factors driving the changes, resembles the national scenario for rural residents in Bangladesh.

The reduced consumption of meat, milk, eggs, fish and vegetables by rural people in shrimp farming areas has serious implications for their health[14,34,86], and reduction in cattle dung for fuel has decreased the frequency of boiling water, thus increasing incidents of water-borne diseases[14]. As the lack of homestead vegetables decreases food security, nutrition and income generation[15], shrimp farming has increased the risk of food shortage and poverty by degrading soil qualities, and threatening the rice ecosystem[31]. Aquaculture products have become more expensive, and so if farmers catch high-value species (which are good protein sources), they sell them and buy cheaper products for their own consumption[86]. Food habits include foods for specific ceremonies, often to build social relations, and the availability of sacrificial animals for the Muslim Eid-ul-Azha festival is reportedly reduced[15].

Due to shrimp aquaculture's negative impacts on livelihood and environment in the coastal areas, it is increasing demands on the government to regulate this production[64] and to impose regulations for rural land-use planning together with local communities, ensuring their economic well-being and food security[31]. Alternative production systems improving soil fertility, increasing production, food consumption and income may be integrated rice/prawn cultures[87–89]. Adding the fish mola to this culture may further increase production[90], and farmers in Bagerhat practicing this system have increased their daily number of meals and intake of food like fish, eggs, meat, milk, fruits and vegetables[75].

Conclusions

The changes in agro-biodiversity, caused by salinity increase in the three study area, had a significant impact on the people's food habits. Shortage of cattle, goats, native chickens and freshwater fish species led to a price increase and reduced the consumption of these salinity-sensitive animal species. Consumption of milk and eggs decreased due to the shortage of cattle and chickens. Broilers, exotic and marine fish species and exotic oils were cheaper than the local equivalents and thus increasingly consumed by the respondents. The consumption of vegetables and seasonal fruits also declined due to lower production in saline conditions. Apart from a possible lack of sufficient amounts of food, these changed food habits may have serious nutritional impacts and increase vulnerability to diseases.

The decisions concerning which livestock, crops and fruit trees to produce do not depend entirely on the farmers. As seen in Putia, the farmers are forced to lease their land to the shrimp owners, and in both Putia and Srifaltala the farmers' ducks were killed by the shrimp owners. Salinity increases, owners of the shrimp farms and economic motives have directly and indirectly changed the farmers' food habits and may cause negative health impacts. The situation is especially serious for the subsistence farmers, i.e., in Putia, who faced reduced production and could not afford to buy food. The lack of certain foods may also have cultural and social impacts as people may lack the food needed for ceremonies used to build social relations among village members. The entire coastal area is facing increasing salinity, partly from the expansion of shrimp farming, causing a change and decrease in livestock, fish, vegetables and fruit trees produced. As documented in this study, the salinity-induced changes in agro-biodiversity indirectly changes people's food habits. Thus, if salinity continues to increase in Bangladesh, it is likely that similar changes in food habits (as outlined in this study), with possible serious nutritional and health consequences for vulnerable people, will spread.

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Profiling alternative food system supporters: The personal and social basis of local and organic food support

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Abstract

Consumers appear increasingly interested in how to engage in consumptive practices that lead to a more sustainable food and agricultural system. In this paper, we examine two possible consumptive pathways for achieving sustainability: the purchase of organic foods and/or the purchase of local foods. While there is some debate regarding the integrity and sustainability of organic versus locally produced foods, there is limited information examining the similarities or differences among consumers variably interested in one or the other attribute. Using data from a statewide survey of Ohio, USA, respondents and members of a food cooperative and an environmental and social responsibility organization, a typology is proposed and comparisons are made among different types of local and organic food consumers regarding their attitudes about food, agriculture and the environment. While a large proportion of the survey respondents expressed little or only modest interest in either local or organic foods, distinct groups of respondents interested in primarily the local attribute, primarily the organic attribute, and both attributes are identified. The results reveal similarities and differences across types with the profiles of each type of consumer contributing to a more nuanced view of supporters of these foods that can assist in production decisions, as well as purchasing and marketing decisions among retailers.

Key words: local food, organic food, consumers, alternative food systems, sustainable food

Introduction

As consumer interest in alternative food systems (AFS) has grown in tandem with a proliferation of diverse food attribute labels (such as organic, local, humane, fair trade, etc.), a question that emerges is the extent to which alternative food consumers vary according to the particular food attribute(s) and associated labels they prefer[1]. A better understanding of alternative food consumer's preferences could help farmers and food retail/market managers determine what to grow, and help food retail market managers and buyers decide what to stock and how to promote or market their food products. From an academic standpoint, knowing which alternative food system attributes or combination of attributes are desired by various consumer subpopulations, and the personal and social basis of these preferences, is needed to understand the trajectory of the alternative food system movement and the characteristics of movement adherents.

This research seeks to investigate the pattern of consumer support and interest in two prominent AFS attributes, local and organic, and to assess the personal and social basis of interest in these two attributes. Drawing on data from a mail survey of the general population of Ohio and data from a mail survey of members of an alternative food co-op located in one Ohio City, we propose a typology distinguishing consumers according to their level of support or interest in local and organic foods. This typology accounts for the fact that some consumers may prefer one or the other attribute (organic or local), both attributes (organic and local) or neither attribute. We then compare and contrast select demographic and social characteristics of consumers according to how they were classified.

Recent Developments in Organic and Local Foods

While the production and consumption of organic foods first attracted interest among the counterculture; today there is increased support among mainstream consumers for

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these foods[1]. US consumer demand for organic foods has been increasing steadily with estimated annual sales growth of between 17 and 21% since 1997[2,3]. In 2005, organic food sales were estimated at $13.8 billion with more recent sales estimated at $23.6 billion[4]. Experts estimate that this pattern of growth will continue as more consumers seek out these foods.

While organic food production and consumption have increased, there also has emerged discontent among some regarding how the organic food system is evolving. One of the most contentious aspects of the organic food system's development of the last decade has been its regulation[5]. In the US, the development and formalization of national organic standards have been viewed by some critics as undermining the longstanding traditions of organic philosophy and practice[6,7]. At one point in the process of developing national standards, substantial controversy arose from the disparity between the technical definition of organic initially released by the United States Department of Agriculture (USDA) and the recommendations of the National Organic Standards Board (NOSB)[7]. According to critics, what was released by the USDA did not reflect NOSB recommendations and allowed a number of substances, as well as genetically modified organisms, sewage sludge and food irradiation to be included as organic. These allowances (and other issues) that did not uphold the integrity of organic as understood by many longtime sustainable agriculture and organic food system participants led to an onslaught of public comment and criticism of USDA and the proposed standards.

While the proposed rules were revised, some critics contend that the ultimate organic food standard adopted by USDA reflects a narrow understanding of organic as the presence or absence of certain substances and does not encapsulate some of the social and economic ideals, such as production occurring via an environmentally friendly system of small- and medium-scale independent producers serving local markets[8,9]. Some AFS advocates are also critical of the emerging organization of the organic food system—with distribution and retailing increasing in scale, global rather than local sites of production, farms that are capital intensive and highly mechanized[9,5].

As organics have become more mainstream and the critique of 'industrial' organic has evolved, locally grown foods (organic or otherwise) and the development of local food systems have emerged as an alternative pathway for achieving a more sustainable and just food system[10,11]. The term 'beyond organic' has gained prominence in the public dialogue to describe the importance of qualities beyond chemical free and to suggest the importance of local food production[12]. Among some local advocates, locally produced foods are deemed superior to certified organic because they embody a commitment to an economically, environmentally and socially sustainable system of agriculture and food production that is reliant on local resources and serves local markets and consumers, whereas organic production has become more about meeting the standardized criteria of organic and capitalizing on the premium that such criteria currently command in the marketplace[13]. There are scholars, however, who caution that it is premature to privilege local over other forms of production, noting that just because food is produced locally does not ensure that it is more ecologically sustainable and socially just[14–16].

Despite this caution, many different attributes of local are touted. An especially prominent argument for local food systems is that the dollars spent on locally produced foods circulates more through the community than dollars spent on foods produced elsewhere by multinational food corporations[17,18]. Another potential benefit of local food systems is that, through closer connections between producers and consumers, a greater respect and a long-term commitment to farming emerge among all food system stakeholders[17,18]. In fact, local food systems are believed to shorten the distance between producers and consumers both spatially and psychologically, allowing a greater trust and confidence in the food system to develop[19]. Local food systems are also argued to privilege small- and medium-scale farm and food businesses because they are less vulnerable to being incorporated into the industrialized food system due to their dependence on direct producer and consumer networks[9].

Personal and Social Basis of Consumer Interest in Organic and Local Foods

The steady growth of the organic sector, the growing interest in local food systems, and some of these debates on the merits of organic versus local that have cropped up in recent years prompt us to investigate whether the same or different subsets of consumers are attracted to the local and organic attributes. A number of agro-food scholars caution against characterizing alternative food system movements as internally coherent and harmonious, rather they might be characterized by competing interests and tensions, although research disentangling differences and similarities has been limited[1,19]. A number of studies have focused on motivations and preferences for one or the other attribute and a review of this research suggests that support for local foods could be motivated by some different factors compared to support for organic production[1,20]. In the next couple of paragraphs, we outline some motivations for local or organic food consumption identified in the research.

One of the factors driving organic food consumption is some consumers' desire food from a production system that does not require the application of synthetic and potentially harmful chemicals to the environment. A number of studies have indeed found an association between environmental concern and organic food consumption[1,21–23]. Organic food consumers are also motivated by food safety concerns. In the modern food system, consumers are increasingly responsible for reflecting on what they will and will not let in their body, leading some consumers to modify their food

consumption practices to manage potential food-related risks[24–26]. Choosing organic foods is a way some consumers choose to manage perceived risks in food production where they perceive residues from chemical sprays, fertilizers, artificial additives and preservatives as possible risks. Several studies have found food safety concern to be an important motivating factor in choosing organic foods[27–30].

Among some consumers, the organic attribute is simply not only less risky but also perceived as healthier[25]. According to DeLind, the absence of chemical residues on or in organically raised and processed food provides organic a reputation for quality among the health conscious[12]. For example, in the Hartman Group's national 2000 Organic Lifestyle Shopper Survey, it was found that 66% of organic food purchasers were motivated by health and nutrition factors[23].

Studies of the motivations behind consumer interest in local foods lags behind that of organic foods, but relationships have been identified between environmental concern, food safety concern and interest in supporting local farming. A number of extant studies have found a positive association between support for local food systems and environmental concern. For example, Hassanein[31] found that 82% of community supported agriculture (CSA) shareholders in Missoula, Montana indicated that one of the personal benefits of being a CSA member was to support efforts to protect the environment[31]. In another study conducted in Iowa, Tegtmeier[32] found a positive and significant correlation between the importance attributed to buying locally grown foods and closely following or monitoring environmental issues.

Purchase of local foods has also been perceived by some consumers as safer. And some suggest that local food systems or practices have grown as a result of anxiety or uncertainty related to the contemporary food system. Historically, perceptions of food quality were often the result of personal observation and social networks in the local community[33]. Knowing where and who has produced a food served as an informal quality assurance program, whereas with mass-produced foods and markets, expert systems of quality assurance now exist devoid of any spatial or personal observation of the consumer. In Tegtmeier's Iowa study of consumers in Black Hawk County, food safety concern had the strongest association with support for buying foods grown locally[32].

While environmental and food safety concerns are common concerns of both local and organic food system supporters, a distinct motivation of some local supporters is their desire to support local farming and farmers. A strong appreciation of local agriculture and a desire to support local farmers, whose loss is perceived as having negative consequences for local communities and their economies, is one reason identified as motivating consumer support of local food systems[34,35]. A number of studies find a relationship between concern for the local community and support for local foods. For example, two early consumer studies found that purchasing locally grown produce was viewed as a way of supporting local farmers and the local economy[36,37]. Other more recent studies have found similar patterns[18,31,38].

While the realization of improved health, improved environmental quality and more vital farming communities are all relatively new criteria consumers weigh, traditional food purchasing considerations remain quite salient for organic and local foods purchases[1]. Intrinsic qualities of food or those things that are physically part of a product, such as taste, nutritional value and appearance, have been identified as important qualities considered by organic or local foods consumers[18]. Price, access and convenience (sometimes referred to as expediency factors) are also typical considerations most studies of food choice have examined and high price, inconvenience and unavailability have all been articulated as factors that may reduce consumer's interest or support of alternative foods[32,39,40].

In sum, this brief review reveals some shared interests and differences in motivations of organic or local food consumption. Organic consumption would appear to have a stronger personal health motivation, while local has a stronger agrarian and community economic motivation. Concern for the environment and food safety concern are likely motivations for both. In our research, we are interested in the relative strengths of these purchasing considerations and preferences and are also curious about the configuration and relative strength of factors that motivate consumers who seek out foods that are both organic and local versus local only or organic only. We also consider the extent to which certain classes or demographics of people are relatively more interested in one attribute or the other.

Research Approach

Our research approach is designed to identify and profile distinct subsets of consumers who are variably interested in the organic and local food attributes. We compare and contrast these subsets of consumers across a range of characteristics. We anticipate that there will be some consumers interested in one or both food attributes as well as consumers with little interest in either. We anticipate that differences will exist among these consumer sets, particularly in terms of environmental, food safety and health concerns as well as their desire to support local farmers. We also consider the extent to which typical food purchasing considerations (taste, price and convenience) are related to preferred food attributes and whether there might be sociodemographic differences among these consumer groups.

From a practical standpoint, our approach leads to the creation of profiles of potentially distinct alternative food system supporters that might inform marketing, procurement and production strategies. From an academic standpoint, we expect there will not only be similarities but also differences that raise questions about the homogeneity of the alternative food system movement.

Data and methods

The data are from the 2004 Ohio Survey of Food, Agriculture, and Environmental Issues, a mail survey focused on measuring food, agricultural and environmental attitudes and from another mail survey of 'Motivated' Food Consumers (MFC). The 2004 Ohio Survey sample consisted of 3500 households located in Ohio, with an equal number of households sampled from rural and urban areas. The sample list was acquired from a private list provider that maintains an extensive household address database. The sample of MFC consisted of 600 households who are members of either a member-owned natural foods grocery store in operation since 1997 or a non-profit educational organization promoting environmental and social responsibility and which also served as the organizational sponsor of a number of local food system initiatives in Central Ohio (many of the households were members of both the co-op and the non-profit organization). For both surveys, the tailored design method guided the data collection process[41]. Five mailings (a pre-notification letter, a cover letter and questionnaire, a reminder postcard, a replacement questionnaire and a final reminder postcard) were sent during the summer and fall of 2004 to the Ohio Survey sample and in winter of 2005 to the MFC sample. A token financial incentive was included in the initial questionnaire mailing of Ohio Survey households to encourage completion and return; however, this was not deemed necessary for MFC Survey households as survey salience was anticipated to be high among this group. A final response rate of 56% was achieved on the Ohio Survey ($n = 1960$) and a 73% response rate for the MFC Survey ($n = 438$).

Typology construction

Segmenting and profiling consumers in an effort to better understand them is a common practice among market researchers. According to Baker and Burnham, markets are segmented by groups of consumers with similar needs and wants[42]. Historically, those who study markets have segmented consumers by age, gender or income. Contemporary consumers, though, are not as easily classified according to these criteria and traditional segmentation criteria must be supplemented with an understanding of socio-cultural or attitudinal factors[43]. Two of the leading consumer research and market analysis firms specializing in health, wellness and natural foods, The Hartman Group and the Natural Marketing Institute, include attitudinal factors in their profiles of consumer segments interested in alternative foods. For example, the Hartman Group delineated four organic consumer types (the organic engaged; the organic attracted; the organic borderline; and the organic uninterested) based on their interest in organic products, their actual purchasing behavior and their attitudes about select health and environmental issues[44]. We follow a similar approach to develop our (consumer) profiles.

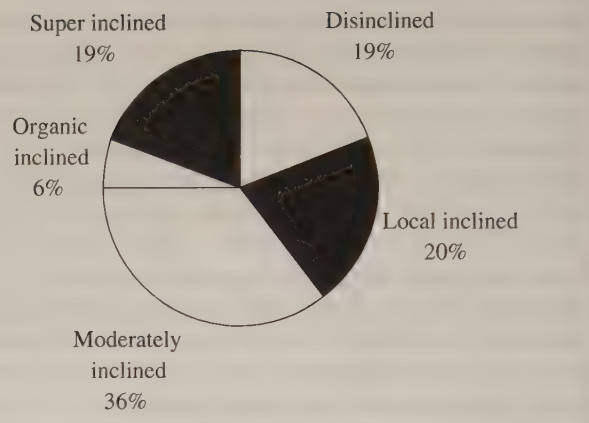

Figure 1. Final clusters or types identified using K-means cluster analysis, Ohio Survey.

Cluster analysis techniques in SPSS were utilized to classify Ohio Survey respondents into distinct groups according to their interest in local or organic foods. Cluster analysis is an empirical method of classification used for market segmentation[40,45]. The intent of cluster analysis is to organize the observed data into a taxonomy based on maximizing group attribute similarities and minimizing attribute differences[46]. Cluster analysis aims at identifying structures in data without necessarily explaining why they exist, although subsequent analysis of clusters through multivariate techniques can be pursued to investigate them more closely[47].

Our final cluster solution resulted in respondents being assigned into five clusters based on the level of importance the respondent attributed to either foods being locally grown or produced or labeled organic as a purchasing consideration (with 1 being not important and 7 being very important). One set of respondents rated neither the local nor organic attribute as an important consideration (we refer to them as the 'disinclined (DI),' $n = 342$). Respondents who rated locally grown foods as very important but the organic attribute as not important fall into what we call the 'locally inclined (LI)' cluster ($n = 359$). Respondents reporting a high level of importance to food being labeled organic but not locally grown comprise the 'organically inclined (OI)' cluster ($n = 100$). Respondents reporting a modest level of importance to foods being both locally grown and labeled organic are part of the 'moderately inclined (MI)' cluster ($n = 634$). Respondents rating a high level of importance to foods being both locally grown and labeled organic are labeled the 'superinclined' (SI) cluster ($n = 343$). The percentage of respondents falling within each cluster is represented in Fig. 1.

In their review of validity and cluster analysis, Punj and Stewart indicate that the user of cluster analysis should demonstrate that clusters are related to variables other than those used to generate the solution[45]. Two other measures of support for local and organic foods were utilized to assess the validity of the cluster solution—frequency of purchasing and willingness to pay for local and organic

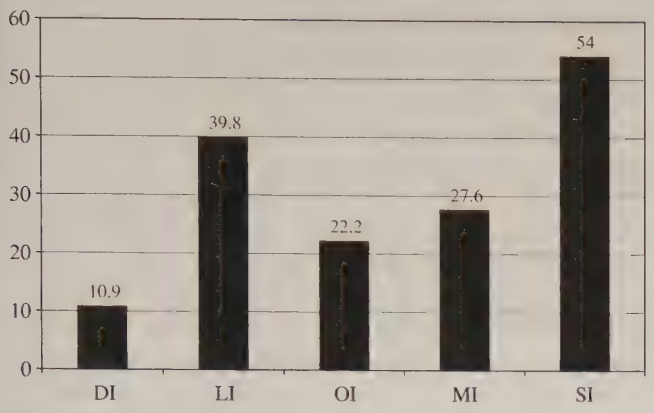

Figure 2. Percent frequently purchasing locally grown or produced foods by consumer types, Ohio Survey (DI = disinclined; LI = locally inclined; OI = organically inclined; MI = moderately inclined; and SI = superinclined).

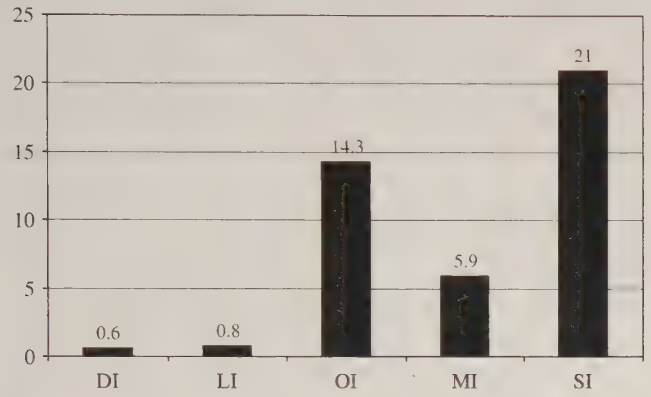

Figure 3. Frequently purchasing organically grown or produced foods by consumer types, Ohio Survey, (DI = disinclined; LI = locally inclined; OI = organically inclined; MI = moderately inclined; and SI = superinclined).

foods were analyzed in relation to the clusters to assess our solution (Figs. 2 and 3). In terms of frequently purchasing foods organically grown or produced, the OI and SI report most frequently purchasing these foods (Fig. 3). Twenty-one percent of the SI cluster and 14% of the OI report frequently purchasing organic foods. Very few DI or LI respondents report frequently purchasing organically grown or produced foods. The pattern of frequency of purchasing local by consumer cluster is presented in Fig. 2. In terms of frequently purchasing local, the DI report less frequently purchasing local (10.9%) and, as expected, the LI group reports more frequently purchasing locally grown or produced foods (39.8%). The SI, or the cluster including individuals rating both local and organic as very important, report most frequently purchasing local (54%).

The pattern of each cluster's willingness to pay for organic or local reveals a similar pattern as purchasing frequency. Those favorable toward the organic attribute are more willing to pay more for organic. Over half of the OI (56%) and SI (53.9%) report a willingness to pay more for organic and just half of the MI are willing to pay more.

Table 1. Percent willing to pay more for organic and local by consumer types, Ohio survey (DI = disinclined; LI = locally inclined; OI = organically inclined; MI = moderately inclined; and SI = superinclined).

	DI	LI	OI	MI	SI
Organic					
10% more	17.8	17.9	35.0	44.6	36.0
25% more	1.5	1.1	21.0	5.0	15.3
50% more	0.0	0.3	0.0	0.5	2.6
Local					
10% more	31.6	58.5	40.8	53.7	55.0
25% more	4.1	9.2	6.1	6.9	12.3
50% more	0.3	0.6	1.0	0.3	2.9

A majority of the DI and LI are not willing to pay more for organic foods (80.7 and 80.7%, respectively). The OI and the SI are most willing to pay greater than 10% or more for organic compared to the other groups. In terms of willingness to pay more for locally grown or produced foods, a similar pattern exists, with the LI group reporting a willingness to pay more for these foods, which is similar to those rating both the local and organic attribute as a very important purchasing consideration. Over half of the LI (68%), the MI (60.9%) and the SI (70.2%) clusters report a willingness to pay more for these foods. The DI are least willing to pay more and only about half of the OI are willing to pay more for these foods. A larger percentage of LI and SI report a willingness to pay 10% or more for foods grown locally. Table 1 shows the percentage willing to pay a premium for organic and local. Overall, the patterns of purchasing and willingness to pay for local and/or organic validate the cluster solution.

To further situate support for local and organic foods in the general population, we include comparisons with a reference group of MFC, who are known to have enrolled in 'movement' style alternative food system organizations. By including the MFC, we are able to make comparisons among those supportive of AFS in the general population and an even more refined subpopulation, persons known to be engaged in alternative food networks. This helps to fill a significant gap in our understanding of support for AFS and provides an even more nuanced picture of the possible heterogeneity of consumer support for sustainable or AFS.

Comparisons and measurement of variables

In an effort to develop profiles of consumer support for local and organic foods, we focus on three sets of comparisons: socio-demographics, purchasing considerations, and agricultural, environmental, and food attitudes or concerns. A number of socio-demographic items are compared, including age and education of survey respondents. Most studies of food-purchasing behaviors also include items that measure the relative importance of a number of intrinsic food qualities. Respondents to both the Ohio and MFC surveys were asked to rate on a scale of 1 to 7 (with 1 being

not important and 7 being very important) the importance of price, availability of food products where they normally shop, taste and nutritional value as purchasing considerations. Four sets of attitudes and/or concerns are also included.

To measure food safety concerns, respondents were asked their level of agreement (five response categories ranging from 5 = strongly agree to 1 = strongly disagree) to three statements related to food safety concerns. The statements were 'Food is not as safe as it was 10 years ago,' 'Food safety is a major concern of mine,' and 'Biotechnology is having a negative impact on the food supply.'

A diet health consciousness scale comprising six items was constructed to measure the extent to which individuals actively reflect on the relationship between their diet and health and their role in using diet to affect their health. This scale had Cronbach's alpha of 0.86 with scale scores ranging from 6 to 30, with lower scores indicating less diet health consciousness and higher scores indicating stronger diet health consciousness. Respondents were asked to indicate on a scale of 1 to 5 (1 = strongly disagree; 5 = strongly agree) their level of agreement with a number of health and diet statements. The items measuring diet health consciousness include: My eating habits are more healthy than others I know; I consider myself health conscious; I am interested in using food to maintain good health; I am interested in using food to prevent disease; I am knowledgeable of the health benefits of foods I eat; and I usually look for health information when I buy food products.

An additive scale comprising five items was created to measure agro-environmental concern. The scale has Cronbach's alpha of 0.76 and scores ranging from 5 to 35 with lower scores indicating less agro-environmental concern and higher scores indicating greater levels of agro-environmental concern. The questions combined to assess agro-environmental concern asked respondents to indicate on a scale of 1 to 7 (1 = Not Concerned; 7 = Very Concerned) their level of concern with a number of agro-environmental issues in the news in the past year. The items used for this measure include: global warming, pollution of Ohio's rivers, streams or groundwater; mad cow disease; development of large-scale poultry and livestock facilities in Ohio; and genetic modification of plants.

To measure concern for local farmers and rural communities four attitudinal items are included. The first two items assess the importance of agriculture for Ohio's economy and quality of life. Respondents were asked to indicate their level of agreement with the following statements (five response categories ranging from 5 = strongly agree to 1 = strongly disagree): 'Ohio's economy will suffer if the state continues to lose farmers' and 'Overall, farming positively contributes to the quality of life in Ohio.' The other two items measuring sympathy for farming and farmers asked respondents to indicate their level of concern (seven response categories ranging from 7 = very concerned to 1 = not concerned) about the loss of farmland as a result of urban growth and the loss of family farmers.

Results and Discussion

We now turn our attention to profiling each of the five consumer types identified in our general population as well as the motivated consumers (the members of an alternative food co-op or non-profit educational organization promoting environmental and social responsibility). We describe the characteristics of each consumer type, highlighting similarities and differences among the various types. Because we anticipated some concern and attitudinal differences, we are able to consider the extent to which the various consumer types conform to our expectations. We conclude our profiles with a synthetic summary of key patterns identified and questions we have for future consideration.

Consumer profiles: DI

DI consumers (19% of the respondents) are interested in neither the local nor organic attribute. Not surprisingly, they reported the lowest level of agreement with all three food safety concern questions and the lowest level of diet health consciousness, the lowest level of agro-environmental concern, and the lowest level of farmer and farming concern (Table 4). In terms of standard food purchasing considerations, they rated price, availability where they normally shop, and taste as important considerations, comparable with the MI, LI and SI groups. On the other hand, they rated nutritional value and added health benefits beyond basic nutrition as less important purchasing considerations than any of the other consumer types.

DI's attention to traditional purchasing considerations but limited sympathy for contemporary food, environmental and farming issues suggests that these are not alternative food consumers seeking to realize various social and personal goals via food consumption beyond basic sustenance. Demographically, our data do not reveal any sharp distinctions from the other consumer groups (Table 2). Because we do not know what this group's perceptions of local and organic are, future qualitative research might investigate this group more closely to understand their view of these attributes as well as their overall view of food's connection to health.

MI

The MI were the largest consumer type identified, comprising 36% of the respondents. As their name suggests, they have a moderate interest in local and organic foods. Comparatively, they reported moderate food safety concern, diet health consciousness, agro-environmental concern and farmer and farming concern (Table 4). They rate price, availability where they normally shop and taste as important considerations at similar levels as the DI and LI (Table 3). Nutritional value and added health benefits beyond basic nutrition were rated moderately important compared to the other groups. Demographically, the MI was quite similar to the DI, LI and OI (Table 2). The sheer size of this group and their modest interest makes them a

Table 2. Socio-demographic comparisons across clusters and MFC (DI = disinclined; LI = locally inclined; OI = organically inclined; MI = moderately inclined; SI = superinclined; MFC = motivated food consumer).

	DI (342)	LI (359)	OI (100)	MI (634)	SI (343)	MFC (438)	*F*-test or Pearson χ-square	Post-hoc tests
Socio-demographics								
Female (%)	46.2	56.1	42.9	51.7	52.5	65.1	17.3[2]	
Age	49.1	49.1	48.0	48.0	56.0	46.4	12.6[1]	SI>DI,LI,OI,MI
White (%)	94.3	95.7	78.6	85.9	85.6	93.2	77.1[2]	
Education	14.5	13.9	14.1	14.3	13.2	17.1	10.5[1]	LI < DI,MI; SI < DI,OI,LI,MI
Children in household (%)	33.9	38.4	42.0	36.4	29.7	21.9	8.9	
Employment Status (%)							64.9[2]	
Employed full/part-time	69.3	65.9	69.1	66.6	51.2	77.4		
Retired	18.5	24.1	18.6	20.9	36.1	10.6		
Not in paid workforce	10.2	8.8	8.3	9.2	11.5	12.1		
Household Income (%)							74.6[2]	
Less than $9999	6.1	3.0	6.7	5.4	5.8	3.8		
$10,000 to 19,999	8.7	9.7	7.8	10.4	15.2	9.9		
$20,000–34,999	17.8	17.6	24.4	17.5	29.0	13.2		
$35,000–49,999	13.9	20.4	18.9	19.2	17.7	18.4		
$50,000–74,999	28.5	25.2	15.6	22.1	18.7	25.2		
$75,000–99,999	9.4	11.9	6.7	13.4	9.7	15.1		
$100,000 or more	15.5	12.2	20.0	11.9	3.9	14.4		
Social connection to farming								
Grew up in a rural area (%)	21.1	29.4	19.4	23.8	28.7	14.3	42.3[2]	
Converses with a farmer	4.1	5.5	2.6	3.5	4.3	2.8	4.3[1]	LI>DI,OI,MI

[1] *F*-test significant at 0.05-level.
[2] Pearson χ^2 statistic significant at 0.05-level.

Table 3. Other food purchasing considerations across consumer types (DI = disinclined; LI = locally inclined; OI = organically inclined; MI = moderately inclined; SI = superinclined; and MFC = motivated food consumer).

	DI	LI	OI	MI	SI	MFC	*F*-test	Post-hoc tests
Price	5.7	5.8	5.5	5.7	6.2	4.9	8.2[1]	LI>OI; LI,DI,OI,MI < SI
Available where normally shop	5.6	5.8	5.5	5.7	6.2	5.4	11.6[1]	LI>DI,OI; LI,DI,OI,MI < SI
Taste	6.4	6.5	6.3	6.4	6.6	6.2	6.2[1]	LI>DI,OI,MI; SI>DI,OI,MI
Nutritional value	5.4	5.5	6.0	5.8	6.4	6.4	39.0[1]	DI,LI < OI,MI,SI; SI>OI,MI
Added health benefits beyond basic nutrition	4.7	5.0	5.6	5.4	6.2	5.7	67.3[1]	LI,OI,MI,SI>DI; LI < OI,MI,SI; OI,MI < SI

[1] *F*-test significant at 0.05-level.

potential target for those interested in expanding the local or organic customer base.

LI

The LI (20% of the respondents) rated local as an important food attribute, but not organic. Compared to the OI and the SI, the LI expressed lower food safety concern, diet health consciousness and agro-environmental concern (Table 4). They did express relatively high farm and farming concern (not quite as high as the SI) (Table 4). The importance they place on price, availability where they normally shop and taste are comparable to the levels reported by the DI and MI. The importance they place on nutritional value and added health benefits beyond basic nutrition is comparable to the DI and lower than the OI, MI and SI (Table 3). Demographically, the LI are less educated than the MI or SI (Table 2). A relatively high proportion of the LI grew up in a rural area and they are the most likely to regularly converse with a farmer.

In general, the LI appear to represent a consumer population that has an affinity for agriculture and farming, and their support of local may be a manifestation of that sentiment. On the other hand, their level of concern for food safety and health situates them near the DI and MI and might explain their low affinity for the organic attribute. As will become apparent in profiling the SI, this is one of two quite distinct consumer subtypes attracted to the local attribute. The existence of two distinct types is consistent with studies comparing consumers in four counties in

Table 4. Personal and social attitudes/concerns by consumer type (DI = disinclined; LI = locally inclined; OI = organically inclined; MI = moderately inclined; SI = superinclined; and MFC = motivated food consumer)

Attitudes	DI	LI	OI	MI	SI	MFC	*F*-test	Post-hoc tests
Food safety concern								
Food is not as safe as it was 10 years ago	3.1	3.1	3.6	3.2	3.7	3.8	14.5[1]	DI,LI,MI < OI,SI
Food safety is a major concern of mine	3.8	4.0	4.2	4.1	4.6	4.2	41.8[1]	DI < LI,OI,MI,SI; LI < OI,MI,SI; OI,MI < SI
Biotechnology is having a negative impact on the food supply	2.8	2.9	3.0	2.9	3.3	3.9	13.1[1]	DI < LI,OI,MI,SI; LI,OI,MI < SI
Diet health consciousness	20.8	21.4	23.5	22.2	24.2	25.6	30.6[1]	LI>DI; DI,LI < OI,MI,SI; OI,SI>MI
My eating habits are more healthy than others I know	3.3	3.4	3.7	3.5	3.9		21.9[1]	LI < OI,SI; DI < OI,MI,SI; MI < OI,SI
I consider myself health conscious	3.4	3.5	4.0	3.7	4.0		27.2	DI,LI < OI,MI,SI; MI < OI,SI
I am interested in using food to maintain good health	3.8	3.9	4.2	4.0	4.3		26.7[1]	DI,LI < OI,MI,SI; MI < OI,SI
I am interested in using food to prevent disease	3.6	3.8	4.2	3.9	4.2		33.0[1]	DI < LI,OI,MI,SI; LI < OI,MI,SI; MI < OI,SI
I am knowledgeable of the health benefits of foods I eat	3.5	3.6	3.8	3.7	4.1		23.7[1]	DI < LI,OI,MI,SI; LI,MI < SI
I usually look for health information when I buy food products	3.1	3.3	3.7	3.5	3.9		33.9[1]	DI < OI,MI,SI; LI < OI,MI,SI; MI < SI
Agroenvironmental concern	20.3	22.8	25.3	24.3	27.6	28.7	76.7[1]	SI,MI,LI>DI; LI,MI < OI; OI < SI
Global warming	3.7	4.2	4.6	4.5	5.0		24.2[1]	DI < LI,OI,MI,SI; SI>LI,MI; OI>LI
Pollution of Ohio's rivers, streams or groundwater	5.4	5.6	6.1	5.8	6.2		20.5[1]	DI < LI,OI,MI,SI; SI,OI>LI,MI
Mad cow disease	3.8	4.3	5.1	4.8	5.6		39.4[1]	DI < LI,OI,MI,SI; LI < OI,MI,SI; MI,OI < SI
Development of large-scale poultry and livestock production facilities in Ohio	3.7	4.3	4.6	4.6	5.3		37.9[1]	DI < LI,OI,MI,SI; LI < MI,SI; OI,MI < SI
Genetic modification of plants	3.7	4.3	4.7	4.6	5.5		41.0[1]	DI < LI,OI,MI,SI; LI < MI,SI; OI,MI < SI
Farmer and farming concern	17.9	19.8	18.6	19.1	21.0	20.5	42.7[1]	DI < LI,OI,MI,SI; OI,MI < LI,SI; MI>OI; SI>LI
Ohio's economy will suffer if the state continues to lose farmers	3.9	4.2	3.9	4.1	4.5		24.6[1]	SI>DI,LI,OI,MI; LI>DI,OI,MI; MI>DI
Overall, farming positively contributes to the quality of life in Ohio	4.2	4.4	4.0	4.1	4.3		9.5[1]	SI,LI>DI,OI,MI; OI>DI
Loss of farmland as a result of urban growth	5.0	5.6	5.3	5.4	6.0		20.9[1]	DI < LI,OI,MI,SI; LI>MI; LI,OI,MI < SI
The loss of family farmers	4.9	5.7	5.4	5.5	6.3		44.3[1]	DI < LI,OI,MI,SI; LI>OI,MI; SI>LI,OI,MI

[1] *F*-test significant at 0.05-level.

Washington, USA and documenting distinct local food meanings and constituencies[48]. It also raises some interesting questions about the extent to which the local attribute represents a food attribute valued for where it is produced, versus its transformative potential to reconstruct a more sustainable food system[40,18].

OI

The OI represents the smallest consumer type identified (only 6% of respondents), but they are quite distinct. They report comparatively high levels of food safety concern, diet health consciousness and agro-environmental concern, but not quite as high as the SI consumer type (Table 4). They report relatively low levels of farmer and farming concern (not quite as low as the DI). Price, availability where they normally shop and taste are rated as important, but not as important as any of the other consumer types (Table 2). Nutritional value and added health benefits beyond basic nutrition are rated as more important than the DI, LI and MI, but not as high as the SI. A relatively smaller proportion of OI report having grown up in a rural area and they report the lowest frequency of conversing with a farmer.

The OI, as might be expected, are distinct from the LI in their high evaluation of added health benefits and nutrition, concern for food safety and the environment, while expressing low concern for farmers and reporting the greatest social distance from farming. The OI may be more apt to seek out the food attributes they desire, as price and availability where they normally shop are not rated as important purchasing considerations compared to the LI.

SI

The final consumer type identified in the general population, the SI, valued both the organic and the local attribute (19% of respondents). As would be expected of consumers valuing both these alternative food attributes, the SI are the most concerned about food safety, the most diet health conscious, have the greatest agro-environmental concern and expressed the greatest concern for farmers and farming. Despite their strong personal and social concerns about food, health, the environment and farming, the SI rate price and availability where they normally shop as more important than any of the other general population consumer types identified. They also rate taste, nutritional value and added health benefits beyond basic nutrition as very important as well.

Demographically, the SI were the most distinct of any of the consumer types identified, being the oldest, having relatively lower levels of education, a high proportion retired and their income levels were relatively low compared to the other groups. A high proportion (about as a high as the LI) grew up in a rural area and they reported relatively frequent conversations with farmers (but not as high as the LI).

The strong levels of personal and social concern were anticipated but the price consciousness and the convenience preference (available where they normally shop) were not expected. Despite this latter finding, the SI encompasses some of the concerns of the LI and the OI. There are some interesting demographic qualities to the SI, particularly their age. Future research might explore this finding in greater detail, especially the extent to which this finding might be a life course outcome (as persons age they become more sensitive to the foods they consume) or a generational issue (older generation more interested in unprocessed foods often associated with some alternative food products).

MFC

The final group we profile are the MFC we surveyed from a food co-op and non-profit educational organization in one Ohio city. In many ways they mirror the SI group identified from the general population, with a couple of critical differences. In terms of personal and social attitudes, they were more diet health conscious and more concerned than any of the general population types about food safety and the agro-environment. They were concerned about farmers and farming, but not quite as strongly as the SI. The importance of availability where they normally shop was of lower importance than for any of the other groups and price was a much lower consideration compared to the other consumer types. Demographically, the MFC were more educated, reported higher levels of income and a much higher percentage of motivated consumers were female. They also appear to be more socially distant from farming, with a much lower percentage reporting growing up in a rural area and they also report lower frequency of conversing with a farmer (at a level comparable to the OI).

It may be that the motivated consumers identified and surveyed in our study represent a subtype of the SI, which raises interesting questions about the potential heterogeneity of alternative food consumers who differentially access foods that conform to their ideals. In general, the MFC appear to be similar to the SI, but are not as price and convenience conscious. The motivated consumers may have the luxury of additional income, allowing them to be less price conscious compared to the SI. The high proportion of females among the motivated consumers might be because food shopping is traditionally a woman's activity and thus membership in the co-op might be skewed toward the female shopper. The relatively weak social connections to farming and rural places among the motivated consumers is interesting, given they do report reasonably high levels of concern for farmers and farming.

Conclusions and Future Research

Our cluster analysis utilizing the local and organic food attributes resulted in an intuitive and logical set of consumer groups. The cluster analysis results reveal consumers

valuing the local attribute distinct from the organic attribute and a large segment of consumers favorable toward both attributes. This cluster solution suggests that a sizable subpopulation exists interested in local, but not excited by the organic attribute, as well as a sizable subpopulation interested in both the local and organic attribute (although we are unable to determine from our data the extent to which both attributes are simultaneously desired by these consumers). One limitation to be noted is that our data are from two Ohio-based mail surveys conducted several years prior to the economic downturn. Generalizations based on these results to consumers outside of Ohio should be made with caution; although, our results provide a benchmark for exploring patterns of interest and support in other areas. While the results are still timely in that they distinguish consumer interest in local from organic, the economic downturn has likely increased all consumers' interest in price as a purchasing consideration and may be perceived as a much greater barrier for purchasing local and organic foods than when the data were originally collected for this study. Future research should explore the impact of the downturn on consumer perceptions and interest in local and organic foods and, specifically, in what ways is consumption and support of local foods impacted differently than support and consumption of organic foods. In terms of the discourse related to the decoupling of local from organic and the importance of both characteristics in definitions of sustainable agriculture, these results suggest that there may be market segments seeking production that satisfies one or the other or both criteria.

Consistent with our expectations, and shedding light on the diversity among alternative food system supporters, the profiles document some systematic differences among local and organic supporters. Organic supporters are more agro-environmentally concerned, more diet health conscious, and more concerned about food safety than the LI. The LI are more concerned about local farmers and rural communities than OI consumers. From a practical standpoint, these attitudinal differences point to the importance of developing marketing and communication strategies addressing or aligning well with these concerns.

Some critical considerations and questions emerge with regard to these findings, especially pertaining to future local food system development. On the practical side, the results suggest that there may be two different routes for promoting local foods, one through appeals to support local farmers and the other appealing to the triumvirate of local farmer support, diet-health benefits and environmental benefits. Promotion of diet-health benefits and environmental benefits draws the organic attribute into the mix as well. An interesting question that might be probed further is the extent to which the local-only crowd might actually be reluctant or repelled by the organic attribute (a possibility suggested by the fact local is valued but not organic by some consumers), but untestable with our data. Future research should probe the local food system support among different subsets of consumers qualitatively, as our measurement approach forced responses to closed ended questions and it would be interesting to learn how different subsets might express their motivations without the restrictions of a mail survey instrument.

With regard to local foods and availability, the findings suggest that even if there are high levels of support for local foods, having to go out of your way to purchase them (an inconvenience) may pose a significant barrier to a substantial proportion of potentially supportive consumers. If local foods are not convenient to purchase, then growing the market and movement for these foods may be difficult beyond the most motivated. The fact that price and availability are important purchasing considerations for many local food consumers also raises questions about maintaining the social and environmental ideals sometimes associated with local production, while seeking to mainstream local and getting products on traditional grocery shelves at competitive prices. Also, mass production of local produce (which may be necessary to overcome issues of availability and price) may benefit certain classes or scales of producers not currently associated with niche and farmer's market outlets and even undercut the price needs of these traditional local food producers.

Another interesting question related to the desire to support local farmers via local food purchases has to do with the growing social distance from farming among the US population. As people become further and further removed from agriculture, the critical question will be whether or not supporting rural people, farmers and rural places will continue to be valued and whether or not this is a frame that will resonate with future generations. Practitioners should be sensitive to this possible generational challenge and future research should address the extent to which views of food and farming change across the life course, but also the extent to which they are tied to particular generational experiences.

Similarly, with regard to the SI, our findings also reveal possible future generational challenges that may pose some unique challenges for practitioners working to increase awareness and consumption of local foods and may impact purchasing decisions among food retailers. Future AFS research should explore reasons for greater interest in local and organic foods among older consumers as we did not anticipate this. Perhaps the association is due to older respondents having greater familiarity and appreciation of minimally processed foods, with locally produced foods most likely being purchased in their basic, unprocessed form. The critical question emerging is whether or not younger generations will be as interested in AFS, especially local foods, as they require knowledge, time and interest in cooking with unprocessed foods.

A number of analysts have noted that the frames used by local advocates must also integrate social justice matters to truly meet expectations beyond organic[49]. One noteworthy limitation of this research is we did not assess attitudes about improving food access or working conditions for farm workers. Future research should consider the

possibility that there might be differences across consumer types with regard to these social justice concerns. These types of comparisons would substantially improve our understanding of AFS supporters and may help to shift some of the focus to other aspects of these systems that have been largely ignored by the organic movement, as well as the newer 'beyond organic movement.'

Finally, with regard to organic supporters, a couple of interesting questions emerge that warrant future attention. If organic supporters are less price conscious (Table 3) and willing to pay more for organic foods (Table 1) and similar attitudinally to the MFC—are they a more loyal or committed consumer to organic than the LI are to local? Will preferences for organic and advocacy for a more sustainable agro-food system embodied in the government sanctioned organic attribute outlast efforts for more localized food systems due to their willingness to pay for attributes believed to contribute to that outcome? Will they become more engaged in groups or organizations supportive of a more sustainable or alternative agro-food system?

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Farmer perceptions of sustainable agriculture practices and drought risk reduction in Nebraska, USA

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Abstract

Social factors, such as farming methods, have an impact on farm vulnerability to drought, but have received little research or policy attention. Some researchers and advocates have argued that sustainable agriculture systems are less vulnerable to climate risk than conventional systems because sustainable agriculture requires producers to have skills promoting adaptability. In this paper, we investigate producers' perceptions on the use of sustainable agriculture in reducing drought risk, and what they believe would help them better adapt to drought. We surveyed and interviewed farmer members of two sustainable agriculture organizations in Nebraska, USA, during a multi-year drought period from 1999 to 2007. Producers reported implementing a range of practices, such as organic soil building techniques, reduced tillage, targeted crop selection and diversification of crop and livestock production systems, to reduce their drought vulnerability. Although some practices were implemented specifically to reduce drought risk, producers felt that the practices they implemented as part of their normal operation were largely responsible for reducing their risk. Respondents held mixed views on the effects of insurance and farm programs on their drought management decisions. Finally, producers indicated that their ability to adapt to drought is limited by a number of barriers, especially a lack of capital and the need to respond to markets and maximize production to maintain cash flows.

Key words: drought, sustainable farming, organic farming, climate, vulnerability

Introduction

The National Climatic Data Center[1] estimates that economic losses from drought and heat waves cost the USA more than $180 billion from 1980 to 2009, with a majority of losses incurred in the agricultural sector. The State of Nebraska's agricultural drought losses alone topped $1.2 billion in 2002, which was the peak of a multi-year drought from 1999 to 2007[2]. These numbers illustrate the high vulnerability of conventional US agriculture to recurrent drought.

Drought becomes a disaster when it overwhelms the capacity of people and the environment to accommodate adverse conditions[3]. The characteristics of populations, activities and the environment that make them susceptible to the effects of drought, referred to as vulnerabilities, are related both to biological/physical and social factors[4]. Biological and physical factors, such as soil type, soil biodiversity, availability of surface or groundwater for irrigation and probability of seasonal crop moisture deficiency, affect a farm's vulnerability to drought[5]. These relationships are fairly straightforward. However, social factors (e.g., the influence of the farmer and the farming system) may be as or more important to a farm's vulnerability to drought, and are less well understood[6]. The literature on natural hazards vulnerability proposes that human factors or coping abilities, such as a farm's asset base, labor capacity, community resources or social capital and manager knowledge may help to lessen an agricultural operation's vulnerability and associated drought impacts[7].

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Along this line of reasoning, it is argued that sustainable agriculture systems may be less vulnerable to climate risk than conventional systems. 'Sustainable agriculture' is defined by the United States Department of Agriculture as 'an integrated system of plant and animal production practices that satisfies food and fiber needs, enhances environmental quality and natural resources, integrates, where appropriate, natural biological cycles and controls, and sustains the economic viability of farm operations'[8]. Another dimension of sustainable agriculture is added by scholars who propose that '... sustainable agriculture is not just a set of practices but a process requiring skills of adaptability' (see Wall and Smit[9], p. 116). In general, the linkages between adaptive capacity in sustainable agriculture systems and reduction of drought risk are not well understood.

In this paper, we explore the effect of sustainable agricultural systems and practices, as well as farm policies and programs, on farm vulnerability to drought. Our research questions include:

- How do producers use sustainable practices as drought mitigation tools?
- Do farmers who use sustainable practices see significant benefits during drought?
- How do insurance and federal farm programs affect the use of sustainable practices to mitigate drought?
- What barriers do producers perceive in using sustainable practices to mitigate drought?

A better understanding of how some agricultural producers use sustainable agriculture practices to mitigate drought will help more producers and advisors better address drought vulnerability in agriculture.

Literature review

Research on organic farming methods demonstrates the connections between improved soil structure, increased organic matter and drought vulnerability. Research trials have shown that organic farming methods can produce higher yields during drought years than conventional (non-organic) farming methods[10,11].

Increased levels of organic matter and improved soil structure, including soil aggregation, have been demonstrated under organic fertility-building schemes, rotation cropping and conservation tillage methods, resulting in greater soil water-holding capacity and infiltration[12–14]. Residue left on the soil surface (through reduced tillage, mulching or use of groundcovers) has been shown to improve drought resilience by decreasing evaporation rates, increasing water infiltration, and reducing raindrop impact and runoff velocity[15,16]. Minimum tillage has also been shown to improve plant-rooting conditions, increasing water-use efficiency[12].

Soil biodiversity, including mycorrhizal associations, has been shown to positively impact water-use efficiency of plants and help plants deal with drought stress[10,17]. Organic farming techniques support biologically active soil; minimum tillage techniques can also increase soil biodiversity[18]. Genetic and crop diversity, in the form of crop rotations, intercropping or integrating livestock, have been shown to benefit producers in drought-stressed areas by including genotypes, crops or animals that are less sensitive to the stress or that minimize risk under different types of weather[19–21].

Farm adaptability has also been proposed as an important link between sustainable agriculture and drought vulnerability[9,22,23]. Adaptation, defined by Smidt and Skinner[24] (p. 6) as 'adjustments in ecological–social–economic systems in response to actual or expected climatic stimuli, their effects or impacts', is multi-dimensional. For example, adaptations to drought may be carried out in anticipation of, concurrently with, or in response to a drought event. Adaptations may be undertaken for a short-term duration or a long-term duration[24,25].

Smidt and Skinner[24] argue that in order to help agriculture adapt to climate-related risks such as drought, research should focus on increasing the adaptive capacity of producers rather than prescribing specific adaptation measures. Economic conditions and farm programs and policies are two social factors that may positively or negatively impact farmers' ability to adapt to drought. A recent study of organic farmers' views of risk management highlighted an ambivalent relationship between organic producers and federal crop insurance[26]. More research is needed to better understand the adaptive potential of farmers to drought in the context of real-world settings.

Research methods

To explore the relationship between sustainable agriculture practices, farmer adaptation and drought, members of two sustainable agriculture organizations in Nebraska were surveyed and interviewed during the spring and summer of 2005. During this time, producers were still experiencing the lingering effects of a multi-year drought that had begun in 1999 and peaked during 2002, which was the third driest year in Nebraska's recorded history (only 1934 and 1936 were drier). Although causing significant losses and hardship, the severe drought offered an important opportunity to investigate producers' perceptions about impacts to their operations, and how their farming and livestock production methods did or did not lessen the effects of drought.

Producer responses were obtained through a mail survey and follow-up personal interviews drawn from the survey sample. The survey sample included 'mailing list members' of two Nebraska sustainable agriculture organizations: the Nebraska Sustainable Agriculture Society and the Nebraska Organic Crop Improvement Society. The Nebraska Sustainable Agriculture Society is a non-profit membership organization whose mission is to 'promote agriculture and food systems that build healthy land, people, communities

and quality of life for present and future generations' by promoting 'farming practices which decrease soil erosion, increase soil fertility, reduce the need for off-farm inputs, protect natural resources and encourage a diverse landscape'[27]. The Nebraska Organic Crop Improvement Association is a local chapter of OCIA International, a non-profit, member owned, international organic certification agency. OCIA International defines organic agriculture as 'farming that maintains and replenishes soil fertility without the use of pesticides and chemical fertilizers'[28]. Since there is no comprehensive list of farmers in Nebraska who practice sustainable agriculture, it was felt that these mailing lists would represent a good coverage of those producers committed to implementing sustainable practices.

A prototype of the survey instrument was drafted and subsequently tested by a group of ten sustainable farmers and advisors in November of 2004. Once their comments were incorporated and the final survey instrument was completed, it was mailed to the 230 mailing list members across the State of Nebraska, USA, during March of 2005. Thirty of the surveys were either returned as undeliverable or respondents reported it did not apply to them since they were retired or only a supporting member of the organization. This resulted in a sample pool of 200 mailing list members. Of the 200 members, 42 returned the survey for an aggregate response rate of 21%. Thirty-eight of the surveys were considered to be valid because the respondents met the USDA and U.S. Census Bureau definition of a 'farmer' (producing over US$1000 worth of commodities per year), and the survey was adequately completed. This resulted in a return rate of 19%, although an accurate response rate is difficult to quantify because additional people on the mailing lists may also be retired or merely urban financial contributors to the organizations (M. Kleinschmidt, Center for Rural Affairs, personal communication, June 2006). Therefore, the actual response rate may have been larger.

Because the focus of this paper is on crop farming techniques, the authors analyzed a subset of returned surveys from producers who said that they grew crops, excluding those who said that they only grew forage for livestock. This article focuses on the 32 valid surveys returned from those identifying themselves as crop farmers. These producers were asked a mix of open-ended, yes/no, and ranking questions on the following themes:

- What practices have been implemented that would be considered 'sustainable'?
- What practices have been implemented specifically to reduce the effects of drought?
- How effective are these practices in reducing the effects of drought?
- What role do insurance and federal farm programs play in determining management methods during drought years?
- What barriers do sustainable producers experience in attempting to mitigate and respond to drought?

Standard statistical analysis of yes/no and ranking questions was done using Predictive Analysis Software (PASW) Statistics 18. Binomial tests were used to determine significance of respondents 'yes/no' answers to questions about changes during drought and perceptions of the effectiveness of their practices. Paired samples tests were used to determine the significance of differences between reported barriers to using sustainable practices. We used an alpha level of 0.05 for all statistical tests. The responses to open-ended questions were coded by two researchers to identify overarching themes, and compared to ensure inter-coder reliability.

To further explore issues that arose in the survey results, the investigators also conducted personal interviews within the same pool of producers who received the survey. Along with the mail survey, a postcard was mailed to the survey sample, asking them to return the postcard if they were willing to participate in a face-to-face interview. As a result, 15 producers were interviewed between June and August of 2005. The interview process followed a semi-structured format. This technique calls for a general list of open-ended questions to be asked, but is flexible enough to allow the interviewer or informant to follow new leads[29]. During the interviews, producers were asked to expound on ideas mentioned in the previous mail-back survey, including practices they implemented to reduce the effects of drought, the effectiveness of these practices and what barriers they encounter. The interviews were tape recorded, transcribed and hand coded to highlight themes in the responses. Themes are recurrent and distinctive features of participants' accounts, characterizing particular perceptions and/or experiences, which the researcher sees as relevant to the research question[30]. In a standard cross-case analysis, participant responses to each question were compared to identify major themes and relevant quotes. The interview results are used in this paper to provide contextual depth and specific examples to help explain the survey results.

Survey and Interview Results

Population sample characteristics

Survey respondents ranged from small specialty crop producers to commercial farm operations. Landholdings ranged from under 0.8 ha (2 acres) to 485 ha (1200 acres), with a median size of 67 ha (165 acres). Respondents were between 31 and 88 years of age, with an average age of 52. They reported an average of 27 years of farming experience, with a range of 1–55 years. Twenty-two respondents (69%) held at least a bachelor's degree, a higher percentage than rural Nebraska as a whole (16.9% holding at least a bachelor's degree in 2000)[31].

Gross sales by farm/ranch also varied considerably, with the mode being US$10,000–49,000 (31% of respondents), followed by US$175,000–249,999 (19% of respondents). Respondents' farm/ranch income as a percentage of total household income was evenly distributed from 10 to 100%.

Table 1. Practices respondents have used that they would consider sustainable.

Sustainable practices used	Respondents ($N = 30$)
Crop rotation	
Three-five-year rotations including legumes	19
Organic soil enhancement	
Building organic matter through use of compost, compost teas, mulch, green manures, cover crops and residue, livestock manures or biodynamic methods	15
Integrated livestock and cropping system	
Using livestock to harvest crops or feeding crops to own livestock, using livestock for weed/insect control, raising a diversity of livestock and/or heritage breeds	12
Weed/insect control without or with minimal use of pesticide	
Use of livestock, crop rotations, or tillage for weed control, zone fertility management, use of no herbicides or insecticides	11
Reduced tillage	
No-till, ridge-till, minimum-till, shallow-till and zone tillage	9
Targeted crop and forage selection	
Raising small grains, forage crops and specialty crops	7
Landscape diversification and conservation	
Riparian buffers (forest and grass), terraces to hold top soil, shrubs for wildlife, grasses and trees to promote useful insects and predators, shelter belts for windbreak and woodlot, contour farming and strip cropping to stop erosion	7
Grazing management (rotational grazing)	4
Use of trace minerals	
Gypsum, lime, soft rock phosphate	3
Purchase fewer inputs	
Grow own seed stock and other inputs, do not irrigate	3
Interseeding	
Companion planting, interseeding or underseeding clovers with small grains	
Marketing practices	
Direct to consumer marketing	2
Grow own food	
Other (mentioned once)	
Study other cultural ways (Amish), teach children to earn on the farm, use of drip tape, energy management, subsoil aeration, keep farm size manageable, summer fallow in rotation	2

Fifty-nine percent of respondents were full owners of their property, similar to Nebraska's statewide average in 2007 (50% of Nebraska farmers were full owners)[31].

Of the 32 valid surveys returned, 14 (44%) of the surveys were from producers who raise only grain or vegetable/fruit crops, and 18 (56%) of the surveys were from producers who raised both crops and livestock. Twenty-one (66%) of the respondents produced organic commodities. Crops grown by respondents included corn (*Zea mays* L. var. *indentata*), blue corn (*Z. mays* L. var. *amylacea*), popcorn (*Z. mays* L. var. *everta*), soybeans (*Glycine max* L.), barley (*Hordeum vulgare* L.), alfalfa (*Medicago sativa* L.), spring wheat (*Triticum aestivum* L.), winter wheat (*T. aestivum* L.), oats (*Avena sativa* L.), clover (*Trifolium*), fruits, vegetables and flowers, demonstrating a diversity of crop choice. Livestock raised included cattle, chicken, swine, turkey, sheep and bison.

As shown in Table 1, when asked what practices they had implemented that they would consider 'sustainable', producers reported a wide range of practices that are compatible with the previously cited definitions of sustainable agriculture, such as the use of crop rotations (63% of respondents), organic soil enhancement methods (50%), integrated livestock and cropping systems (40%), minimizing or eliminating chemical insect and weed control (37%), reduced tillage (30%), targeted crop and forage selection (23%) and landscape diversification and conservation practices (23%). Table 1 also provides a list of practices mentioned by 10% or less of the surveyed producers. Although these practices were not mentioned as frequently, they were seen as important sustainable practices.

Practices that reduce the effects of drought

Producers were also asked to report on the types of actions they have implemented with drought risk reduction in mind (Table 2). Eleven respondents (35%) listed organic soil enhancement methods such as the use of compost, mulch, cover crops and green manures to reduce the effects of drought. One producer interviewed said, 'I plant rye [*Secale cereal* L.] into corn [*Z. mays* L. var. *indentata*] and oats [*A. sativa* L.] into soybeans [*G. max* L.] as "green manure". I also use a combination of dry and liquid products, which I apply before planting to add minerals and nutrients to the

Table 2. Practices used specifically to reduce the effects of drought.

Practices used to reduce the effects of drought	Respondents ($N = 31$)
Organic soil enhancement	
Use of compost/humus, compost teas, composted manure, green manure, biodynamic spray, heavy mulch and cover crops to increase soil tilth and organic matter	11
Targeted drought-tolerant crop selections	
Planted small grains, hybrids with drought tolerance and drought-resistant forages	9
Reduced tillage	
Till only when necessary and only shallow, reduce fall tillage, leave maximum residue on surface, no-till, minimum-till and ridge till	7
Grazing management	
Use of rotational grazing, reduced stock cow herd and run more yearlings, additional watering sites for cattle on grass for better utilization of grass, reduced number of animals	6
Crop rotation	
Following rotation, including fallow in rotation ahead of corn for moisture	4
Landscape diversification and conservation	
Terraces (trap/store runoff), shelter belt, grassed waterways and field windbreaks	4
Irrigation	
Invested in drip irrigation, planed gravity irrigation fields, switched from electric to propane for irrigation	4
Use of minerals to build soil	
Build soils via minerals (lime and soft rock), trying to get zinc levels to 10–12 ppm	2
Other (mentioned once)	
Deep tillage with spading machine and sub-soiler to allow roots to run deep, use lightweight tractors and equipment, plant oats early from April 1–15, plant corn after ground is warm, divert road drainage and other runoff onto terraces, more off-farm employment allowed family to 'take' less from farm, side dress fertilizer rather than pre-plant application, use solid seed soybeans (*Glycine max* L.) to reduce cultivation and increase organic matter, raise more poultry and hogs for direct market, borrow less and reduce capital intensity, organic prices help buffer drought effects	

soil. This type of practice helps during drought because you build up the soil allowing more water-holding capacity'.

The use of *specific* (*more drought tolerant*) *crops* was listed by nine respondents (30%), and another four (13%) specifically mentioned using their *crop rotation* to reduce drought risk. For example, a producer noted during the interview that 'small grains have helped us tremendously. Typically, small grains aren't affected as much in drought. You'll have a yield loss, but not a catastrophic yield loss'. Another person said, 'One thing I find is that you need diversity. In a dry year you may lose some on corn [*Z. mays* L. var. *indentata*], but the small grains will get you through. The diversity and rotation pulls you through the dry years'. A producer also described how crop choice helps their grazing system, saying 'I know that if we run out of grass, I'll find someplace else to graze. We can use some of our crops. I think when you're options are open, that's your best insurance'.

Seven survey respondents (23%) mentioned *reduced tillage* to minimize the effect of drought. Several different types of tillage strategies and equipment were described during the personal interviews, all used with the goal of minimizing ground disturbance. One producer described their use of a chisel plow, explaining, 'A chisel plow undercuts the vegetation to leave residue on top to act like a blanket to hold in the moisture. With the chisel plow you don't have to go as deep. I use wide sweeps to cut out the root crown'. Another producer preferred a blade plow, saying 'It just goes under the bottom of the soil and it leaves all the trash and everything on top'. Another used a harrow, saying, 'I prefer larger chunks on the top so that the water can soak in quicker, so what I use is a harrow with long spring tines on it that sort of vibrate and stir the soil around. It loosens the big clods and pushes the soil right up against the bean plants'.

One producer described using several tillage techniques, saying 'I use a ridge till sometimes, a conventional till sometimes, and make use of no-till on a limited basis ... I'd say I kind of use a tillage rotation. I like to use the ridge till because it uses less tilth. Using a ridge till moves last year's weed seeds out of the row, but it does this while maintaining the residue structure. It keeps the residue on top instead of incorporating it so that little moisture is lost during the process. On the dry land though, I keep the ridges lower because you lose less water when the ground is relatively flat'. Another farmer described using zone tillage, explaining, 'with zoned tillage you skip a tillage operation on a hill with low residue to reduce moisture loss and avoid reducing what little residue is there'. Summarizing the goal of minimizing soil disturbance, one producer stated that they 'just cut under the surface. We leave the trash on top. We don't like to disk it deep or work the ground to

Table 3. Comparison of survey responses citing implemented practices such as sustainable and/or drought risk reduction activities.

Practice implemented	Number of respondents who listed the practice	Respondents citing practices as a sustainable and drought risk reduction practice	Respondents citing practice only as a sustainable practice	Respondents citing practice only as a drought risk reduction practice
Crop rotation	19	4	15	0
Organic soil enhancement	17	9	6	2
Crop choice	13	3	4	6
Reduced tillage	11	5	4	2
Weed/insect control without or with minimal use of pesticide	11	0	11	0
Landscape diversification and conservation	9	2	5	2
Grazing management	6	4	0	2
Irrigation	4	1	0	3

death ... We use a no-till planter because we have a lot of trash there ... You want to keep the moisture in the soil'.

Six producers (19%) said that they used their grazing system or reduced stock numbers to mitigate drought impacts. For example, one producer described during their interview how their grazing system helped them, saying,

> Ten years ago when we weren't rotational grazing, it was just 'turn them in the pasture [in late Spring] and come get them in October'. Drought in that situation ... you're feeding hay continuously, not to mention the damage you do to the grass. It would take several years of herbicide treatment to control your outbreaks of thistles and weeds, and that sort of thing. [With] rotational grazing... they're in there for 30 days of grazing before we have to pull them off grass and start grazing corn and that kind of thing ... Consequently, we didn't have to go in and spray our pasture for several years ... That's where I benefit more with a rotational system.

Two other sets of practices were mentioned by four respondents (13%), including: *conservation practices* such as creating windbreaks or establishing grassed waterways or terraces to trap and store runoff, and *focusing more attention on irrigation practices* that use less water (drip irrigation) or alternative sources of energy (e.g., propane). Table 2 lists a wide variety of additional practices that were mentioned two times or less in survey responses.

Table 3 compares the number of times a practice was listed by a producer as either a sustainable practice, a drought risk reduction practice or as both a sustainable practice and a drought practice. The use of crop rotations and minimizing pesticide use were named primarily as sustainable practices. Irrigation was mentioned primarily as a drought risk reduction practice. Most practices, though, including organic soil enhancement, crop choice, reduced tillage, grazing management and landscape diversification/conservation practices were mentioned fairly evenly as both 'sustainable practices' and 'practices that reduce drought risk'. These practices may be implemented by sustainable farmers as general 'sustainable' practices or 'best management practices', while also having benefits during drought. As stated by one producer with respect to building soil organic matter, 'We don't really do it because of planning for a drought, we do it because it's just a really good practice, and it works'.

Adapting during drought

Producers were also asked whether they had made any short-term modifications to their cropping systems and tillage systems during recent drought years. Results were inconclusive with approximately half saying they did modify their cropping or tillage systems during recent drought and half saying they did not.

Those who said that they did modify their tillage systems primarily reported reducing their tillage during recent drought years either by reducing the number of field passes or reducing the amount of ground tilled. During interviews, two producers added that a lack of weed pressure during drought enabled them to cultivate less. In describing their tillage strategy, a producer stated that 'One thing I did different this year, which was specifically because of the drought, was that I disked [only] twice and then chisel plowed the alfalfa [*M. sativa* L.] to save on moisture and gain residue. Then I planted corn [*Z. mays* L. var. *indentata*] into it'. On the other hand, a producer who said that they did not change their tillage system explained that they instead continued to incorporate green manure to build the soil, and thought that was effective enough for retaining soil moisture.

Of the 16 surveyed producers who said that they changed their cropping system during drought, four stated that they planted less corn (*Z. mays* L. var. *indentata*) or none at all, and seven more said that they increased their use of small grains, alternative crops and forages, including milo (*Sorghum bicolor* L. Moench), millet (*Panicum miliaceum* L.), oats (*A. sativa* L.) and sunflowers (*Helianthus annus* L.). In an interview, one producer noted, 'I made the switch from growing the dryland corn [*Z. mays* L. var. *indentata*]

Table 4. Factors identified by producers that reduced their vulnerability to drought.

What is it about your operation which makes you less vulnerable to drought than more traditional agricultural producers?	Number of respondents ($N = 25$)
Enhanced soils	
Higher levels of organic matter, soil structure helps water infiltration, biodynamic soil, 'live' soil	12
Crop rotation/targeted crop choice	
Crop rotation allows for more drought-tolerant crops like millet or sunflowers that reduce total water use	7
Reduced tillage system	
No spring tillage, no-till, shallow cultivation saves moisture	4
Irrigation practices	4
Versatility of livestock and crops	
Options to graze standing crops, flexibility to modify production system	4
Financial strength	
Organic prices help during times of low yield, reduced costs by growing own seed, able to work off-farm when necessary	3
Other (mentioned once)	
Planting oats (*A. sativa* L.) early and corn (*Z. mays* L. var. *indentata*) late, zinc helps with moisture uptake	

to the proso millet [*P. miliaceum* L.]. I also made some changes in my rotation. On my highly erodible dry land, I changed to a millet [*P. miliaceum* L.], wheat [*T. aestivium* L.], and millet [*P. miliaceum* L.] rotation. This allows me to skip a fallow year which makes for less exposure to wind erosion because you don't have reduced residue'. Another provided a specific example of planning for a drought year by stating, 'I went to drought meetings with the extension service starting in February because all the predictions were that things were going to be dry. So ... we were prepared. We didn't plant some ground to crops. We put them into grazing crops like oats [*A. sativa* L.] and forage sorghum [*S. bicolor* L.] and that kind of thing in preparation to keep the cows. That was kind of a primary goal—to keep the cows without having to buy a lot of expensive feed and that kind of thing. So we made it through. It wasn't easy, but we did it'.

While approximately half of respondents reported modifying their cropping systems or rotations during drought, 63% ($P = 0.10$) said that their long-term management goals were not changed. One farmer offered an explanation for not changing during the interview, stating that their long-term goals included preparing for drought, and that they would continue their current rotation to build soils. Another said, 'I decided that the best way to go is to stick with the current crop rotation. Changing the rotation caused too many problems. I felt that there is enough diversity in the crops that some will have a good year and can make up for the ones which have a bad year. I also felt that it is better to make a long-term commitment to some practice as opposed to changing things for the short-term'.

The 31% of producers who said that their long-term management goals were changed cited a number of long-term adaptations they were considering, including adding livestock into their operation, diversifying crop types, using soil moisture information in selecting crops to plant, adding cover crops, digging additional irrigation wells, keeping debt low and taking a 'more conservative approach to everything'. For example, one interviewed farmer noted a desire to diversify into cattle, saying,

> Something I would like to do, and that I've been thinking about recently, is that I want to one day move my operation into having more livestock .... I feel this for two reasons; nutrient cycling and drought tolerance. The cattle can really help the land if managed right; improve the water holding capacity of the soil because of improved nutrient cycling and biology. Also, livestock provides an extra income stream. Plus, if we have a really bad drought in which the crops are too damaged to sell, we could feed them to the livestock. It wouldn't go to waste!

Effectiveness of practices during drought

In order to explore how sustainable farmers felt their practices helped them during drought, they were asked: (1) whether they felt more or less vulnerable to drought than more traditional agricultural producers; (2) whether they felt the practices they had implemented helped to reduce the impacts of drought during recent years; and (3) how they would prove that their practices helped them.

When asked whether they felt more or less vulnerable to drought than more traditional agricultural producers, 90% of producers ($P < 0.001$) felt they were *less vulnerable* to drought. When asked what it was about their operation that makes them feel less vulnerable, the factor most frequently mentioned (12 comments or 48%) was the health and condition of the soil (Table 4). During their interview, one producer reflected

> In 2001, we had a drought year, and I was in a situation where I had to disk in my green manure two times. Now

> usually, especially if you're conventional, you don't do that because you'll lose so much moisture, but I still came out with a higher yield than my conventional neighbor across the way. I had roughly 58 bushel [3641 kg/ha] corn [*Z. mays* L. var. *indentata*] and he had only 50 bushel [3139 kg/ha] corn [*Z. mays* L. var. *indentata*]. I realize that there could have been other factors at head, say the heat and what not, but I think it's because my soil is so healthy that I could get away with losing the moisture.

Seven other producers (28%) said that their crop rotation made them less vulnerable to drought. As stated by one producer in an interview, 'There's been a reduction in our water use because we've gone from all corn (*Zea mays* L. var. *indentata*) to putting in soybeans (*Glycine max* L.), alfalfa (*Medicago sativa* L.) and barley (*Hordeum vulgare* L.)'. Four (16%) others said that having a no-till or reduced tillage system made them feel less vulnerable to drought, with one elaborating that 'no-till plus small grain in rotation makes us less vulnerable due to moisture saving'. Four surveyed farmers also credited the flexibility in their farming system that comes from having both crops and livestock. For example, in terms of diversity, one producer noted in an interview that, 'In a dry year, you may lose some corn (*Zea mays* L. var. *indentata*), but the small grains will get you through. My livestock also add diversity and help during a drought. I have a better cushion in a drought year because I have the premium price and diversity'.

When asked if they felt the practices they had implemented helped to reduce the effects of drought during recent years, again, 80% of the producers surveyed ($P < 0.001$) responded positively that the practices they implemented helped to reduce the negative effects of drought. When asked how the practices had helped, nine producers (53%) said that their practices either helped moisture infiltrate into the soil, the soil hold more water, or prevented water evaporation from the soil. Elaborating on this point in an interview, one producer noted 'The zoned tillage helps me reduce input costs because I don't use as much fuel since I skip passes, and it also helps me conserve water and cover. All of these benefits of zoned tilling are helpful during a drought'. Three producers also said that their practices helped them achieve relatively good yields, and three said that their practices helped them decrease financial risk. Explaining these comments, a producer reported, 'One thing I really notice is that my yields don't fluctuate as much. I'll have some loss in the dry years, but not nearly as much as the conventional guys. My rotation maintains the fertility in the soil, and I have low inputs. So, at the end of the year, the conventional guys barely make a profit after he pays the chemical guys. Also, I get the organic premium on my products. It really helps'.

For the smaller number of producers (20%) who felt drought impacts were not reduced by their practices, reasons included cover crops that never came up, higher seed costs and less income with small grains, and increased weed pressure. Two producers stated that their practices had not been in effect long enough to yet make a difference during drought.

When asked what kind of evidence they could provide if a skeptical new farmer asked them to prove that their drought-related practices helped, 22 producers offered a description of evidence (Table 5). Ten respondents (45%) said that their yields would provide evidence. As described by one producer interviewed, 'Three years ago, 2002, was a very dry year. I had something like 65 bushel/acre [4080 kg/ha] corn [*Z. mays* L. var. *indentata*] while 1.5 miles [2.4 km] southwest of here a conventional friend of mine got 20 bushel/acre [1255 kg/ha] corn [*Z. mays* L. var. *indentata*]. I felt like my practices really reduced my impacts during the drought'. Seven respondents (32%) cited their soil health as evidence of drought resilience, as described in an interview by a producer who stated they could 'show [a] soil test with percent of organic matter. Each percentage point increase in organic matter increases water holding capacity'. Some farmers had a good understanding of the organic matter levels in their fields and measured changes over time. For example, one farmer noted in their interview that the organic matter level of their farm land used to be at 1.2–1.5% but has increased to 4.0–4.7% with changes in their production system over time. Others did not test their organic matter, but said that they could demonstrate evidence of their soil health through visual inspections. For example, one interviewed producer noted, 'You go past my fields and you don't see water puddles ... it soaks in. You go over to the neighbor's chemical [fields] and you'll see water standing in the fields where it can't drain'.

Seven respondents (32%) said that they would share their financial records as evidence that their practices helped during drought. They reported that sustainable producers may have less need for government disaster payments and less production costs resulting in a higher net profit per hectare than conventional producers, which could be examined by researchers. Summarizing the financial benefits, one farmer reported in an interview that they responded to skeptics by saying, 'Go ahead and laugh. I know what I'm taking to the bank'.

Role of insurance and federal farm programs in determining management during drought

Producers were asked what role insurance and federal farm programs play in determining management methods during drought years. The 28 responses to this question were inconclusive, with an even split between insurance and farm programs playing no role in their management during drought (50%) and the producers saying they carried crop insurance (50%). Follow-up interviews helped to clarify this response, with some producers explaining that they either did not enroll in crop insurance or farm programs, and some that they enrolled but did not let them dictate their cropping system. As noted by one producer, 'I keep up my rotation. I pay no attention to the farm programs'. On

Table 5. Responses given as 'proof' of effectiveness of practices during drought.

If a skeptical new farmer or rancher asked you to prove that your drought-related practices helped you during the last few drought years, how could you prove it to them?	**Number ($N = 22$)**
Yield comparison	
Have always had a crop since 1968, farm production and records, crop yields	10
Soil health	
Good moisture profiles in soil, soil test, measure organic matter, soil not as hard during summer as it used to be	7
Financial data	
Eliminated or reduced government disaster payments, cost of production comparison (cost per acre, reduced input costs, lower bills, compare hay invoices and sale bills), made money and paid off debt	7
Not able to prove	3
Other (mentioned once)	
Less personal stress, personal experiences, increased cow herd, healthy plants	

the other hand, another producer stated that they participate and some of the farm programs are beneficial, 'but as far as the direct payments and all that kind of stuff, I just stay up with it—I sign up for it, but I don't make it a part of my decision making'. Specifically in terms of crop insurance, another producer reported that they use the federal crop insurance program because 'it has gotten better. It also opens up some marketing opportunities because we use forward contracts to market grain, and we feel pretty safe about doing that with federal crop [insurance]'. Similarly, another said 'Even though I'm organic, I have the subsidized crop insurance, but I take the minimum amount. I don't really change for the insurance'. Others stated ambivalence toward using insurance and federal farm programs, with one saying 'As far as federal crop insurance, when we start paying that kind of money for rent .... You don't like it, but you just damn near have to use it. Because I borrow money from my banker, too. I'm not going to leave anybody short'.

Overall, in terms of fostering sustainable agriculture and drought readiness, respondents displayed a fairly negative attitude toward federal farm programs. As described by one producer, 'The structure of the farm payments is hurtful and drives up land prices. Also farmers get careless because they can do whatever they want and still get money out of it. They need to rethink some of the hand-outs. With prices so out-of-control it's hard for someone like me to buy new land and make improvements'.

Barriers to drought mitigation

Producers were asked what barriers prevent them from implementing more strategies to reduce drought impacts and to rate them on a scale from 1 (small barrier) to 5 (larger barrier). As shown in Figure 1, the two largest barriers noted were a 'lack of capital to improve operations' and 'markets/need to maximize production'. Eighty-four percent of respondents identified 'lack of capital to improve operation' as a barrier, and gave it a mean ranking of 3.2, which was significantly higher than six other potential barriers. As explained by one producer, 'Sometimes your cash flow overrides your practicality. If you just expand, and you've got a debt load, that's going to have some control over your actions in a drought'. Eighty-one percent also identified 'markets and the need to maximize production' as a barrier and gave it a mean ranking of 2.6, which was significantly higher than four other potential barriers. With regard to maximizing production, one producer noted that 'In the beginning you really want to establish a good rotation, but it's hard when you're only getting a profit on corn and soybeans because of the low demand on small grains'.

Producer recommendations for reducing drought risk

When asked what needs to be done to make Nebraska farmers and livestock producers less vulnerable to drought, the four most common recommendations were for producers to increase practices that improve soil health (6 comments; 26%); for producers to increase the use of, and researchers to increase development of, more drought resistant crops and crop varieties (6 comments; 26%); for producers to change tillage practices to better conserve soil moisture (5 comments; 22%), and for producers to diversify what is grown on the farm (5 comments; 22%).

With regard to soil health, one interviewed farmer made the comment that 'the first thing we have to do is make sure we've got organic content in all of our farm soils up to 5%. ... Using the factory farming system with chemicals, they're burning up the organic matter. There are a lot of these fields out here that are less than 2%, some even less than 1%. They can't hold water for drought-proofing'. Another producer described their emphasis on growing drought resistant crops, saying, 'I feel very strongly that a lot of these, particularly dryland, farmers could do very, very well by looking at other crops than corn [*Z. mays* L. var. *indentata*]. We focus on popcorn [*Z. mays* L. var.

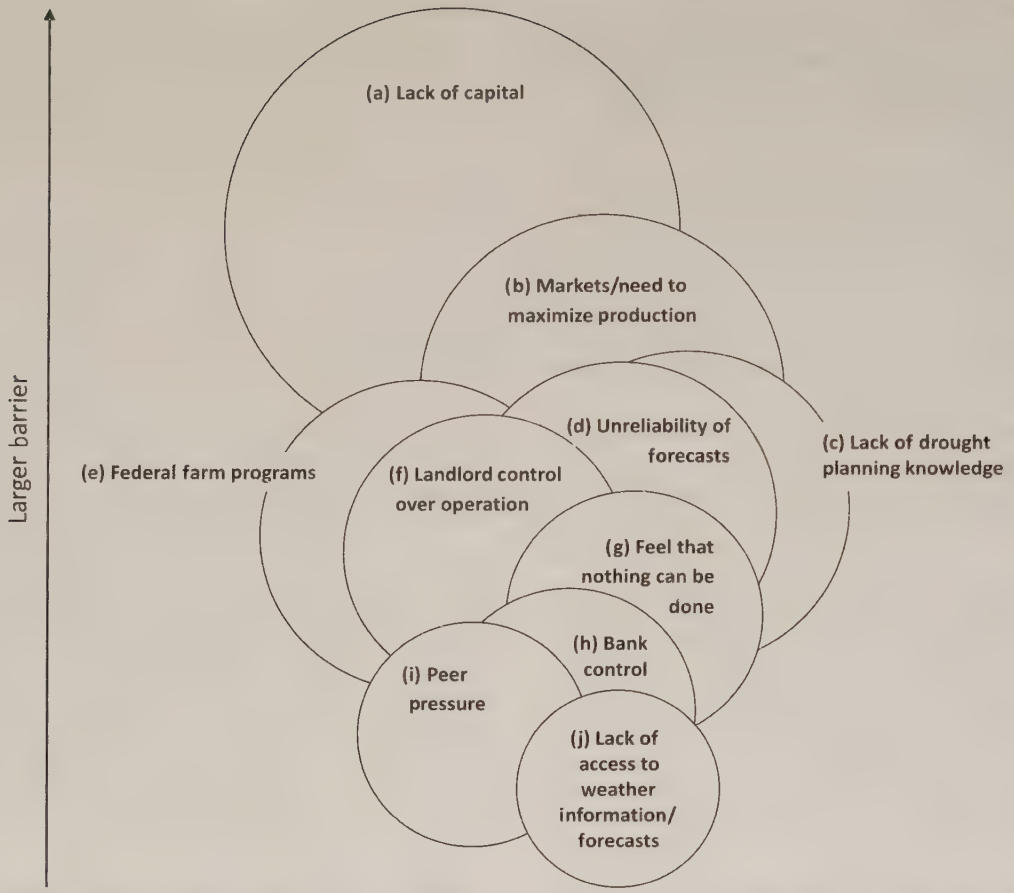
Larger barrier
(a) Lack of capital
(b) Markets/need to maximize production
(c) Lack of drought planning knowledge
(d) Unreliability of forecasts
(e) Federal farm programs
(f) Landlord control over operation
(g) Feel that nothing can be done
(h) Bank control
(i) Peer pressure
(j) Lack of access to weather information/ forecasts

Figure 1. Differences among variables identified by respondents as barriers to implementing drought risk reduction practices (1 = low, 5 = high). (a) Lack of capital ($N = 27$, mean = 3.22, SD = 1.31) was ranked higher than (c) $P = 0.04$, (d) $P = 0.03$, (g) $P = 0.002$, (h) $P = 0.015$, (i) $P = 0.011$ and (j) $P < 0.001$. (b) Markets/need to maximize production ($N = 26$, mean = 2.58, SD = 1.27) was ranked higher than (g) $P = 0.011$, (h) $P = 0.016$, (i) $P = 0.043$ and (j) $P = 0.002$. (c) Lack of drought planning ($N = 25$, mean = 2.28, SD = 1.24) was ranked higher than (i) $P = 0.016$ and (j) $P = 0.011$. (d) Unreliability of forecasts ($N = 25$, mean = 2.2, SD = 1.15) was ranked higher than (i) $P = 0.041$ and (j) $P = 0.001$. (e) Federal farm program ($N = 20$, mean = 2.15, SD = 1.38) was ranked higher than (j) $P = 0.044$. (f) Landlord control over operation ($N = 15$, mean = 2.0, SD = 1.3) was not significantly different than any other variable. (g) Feel that nothing can be done ($N = 21$, mean = 1.81, SD = 0.8136). (h) Bank control over operation ($N = 13$, mean = 1.77, SD = 1.3). (i) Peer pressure ($N = 16$, mean = 1.63, SD = 1.02). (j) Lack of access to weather data and forecasts ($N = 23$, mean = 2.20, SD = 1.15).

everta], which is an extremely valuable crop, which uses one-half to one-third the water. Another good crop we're looking at, because we have the demand for it, is pearl millet [*Pennisetum glaucum* L. R. Br], which is a drought crop. It's a crop that was developed in droughty areas of Africa. ... It has 125% of the feed value of corn [*Z. mays L. var indentata*]'. Another farmer emphasized the importance of diversifying the rotation saying, 'This corn [*Z. mays* L. var *indentata*] and soybean [*G. max* L.] rotation is not a rotation. It's two specialties. There [have] to be green cover crops grown. It's an absolute must, whether you irrigate or not'.

Other recommendations listed by three or fewer respondents included making changes to the US Farm Bill and crop insurance programs to encourage conservation and to support organic production through better crop insurance coverage, moving away from agriculture structures that rely on inputs and 'mine the soil', limiting reliance on irrigation, changing laws around water resources or taxes, better long-term weather forecasting and drought planning education, increasing grass-based farming and rotation grazing, and investing in cloud seeding to enhance rainfall.

Conclusions

The farmers in this study reported implementing a range of sustainable agriculture practices that reduce drought risk, such as organic soil enhancement methods, the use of more drought tolerant crops and crop rotations, reduced tillage, alternative grazing management and land and water conservation strategies. Although it was reported that some strategies were implemented with drought risk reduction in mind, many of the producers argued that the nature of their system provided long-term adaptation benefits for drought vulnerability reduction. They implement many of these strategies primarily as long-term sustainable practices that allow for adaptation to climate and other fluctuations.

Some long-term sustainable practices also enable farmers to make short-term adaptations during drought. For example, crop rotations are a long-term strategy for building soil health requiring an investment in time toward developing markets or market contacts for a variety of crops, as well as time and money to acquire the necessary knowledge, equipment and experience to raise a variety of crops. These long-term strategies and investments allow producers to make short-term adaptations during drought, such as planting more drought-resistant crops or varieties, because marketing contacts, equipment and agronomic knowledge are already in place. Farmers' adaptive capacity to drought may be increased through education about using sustainable practices as a long-term adaptation to drought, and about how sustainable strategies might be used to maximize short-term flexibility during drought.

Lack of capital and the need to maximize crop production and/or produce for existing markets, can be large barriers that keep producers from implementing more strategies to reduce the effects of drought. Lower profits associated with small grains, or the uncertainty of the benefits associated with higher costs for drought-resistant seed or cover crops may also limit producers' implementation of drought strategies. Among other barriers, farm and disaster policies that tacitly encourage farmers not to plan ahead for drought, that financially penalize farmers for taking action to reduce drought impacts, that decrease farmers' options during drought and that lead to impaired soil health and less farm diversity, were also seen as barriers for reducing drought impacts.

To address these barriers, farmers' adaptive capacity to drought may be increased through research and policy initiatives to improve the economic feasibility of using drought-adapted practices. Research needs may include breeding new drought-tolerant varieties of crops, as well as developing profitable uses for crops that are drought tolerant. Policy needs may include programs that provide financial incentives in the way of capital assistance for drought adaptation, market development for drought-tolerant crops and farm program support for alternative crops and sustainable agriculture techniques. Further research assessing the effects of specific farm and food policies on farmers' drought-adaptive capacity is required.

In addition to the research needs described above, additional empirical and case studies should be carried out to further investigate issues expressed in comments made by respondents in this study. For example, more research is needed to investigate anecdotal comments on the extent to which sustainable producers' adaptive capacity helps them during drought events. Comparing the perspectives represented here with those of self-described 'conventional' farmers would also add depth to the discussion of farmer adaptability. As our need to increase global food production grows, it becomes even more necessary to investigate a broad range of alternative strategies for fostering viable production systems and the adaptive capacity to adjust to ever-changing conditions.

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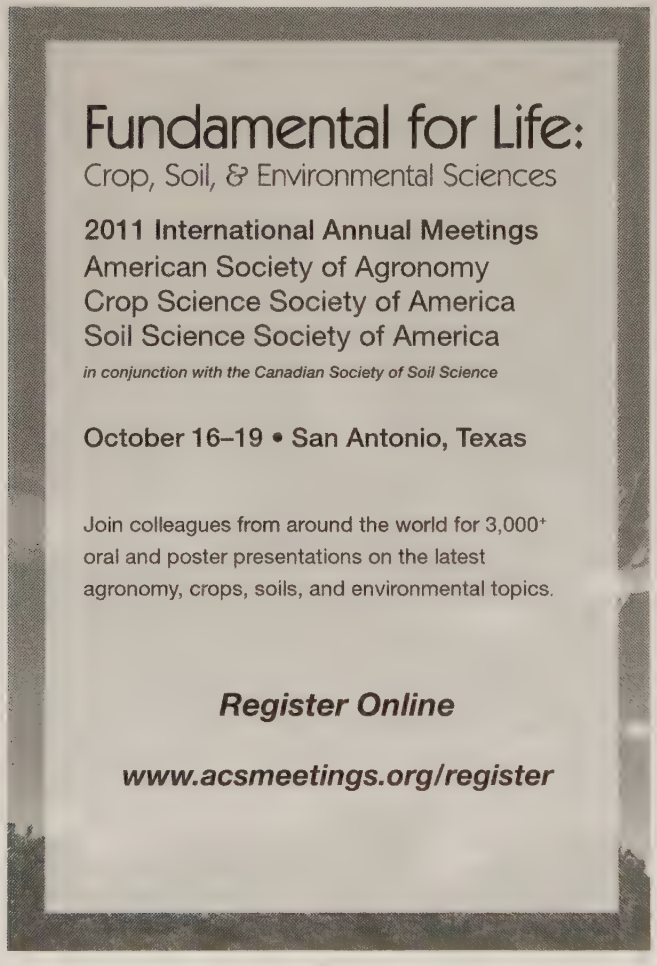
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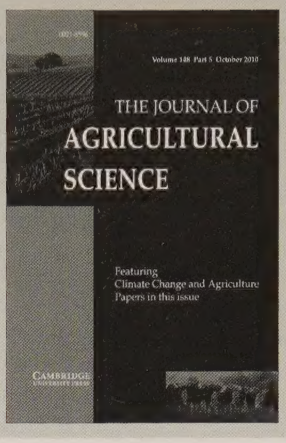

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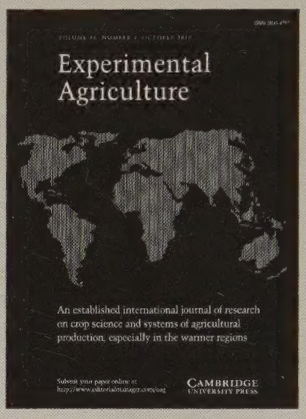
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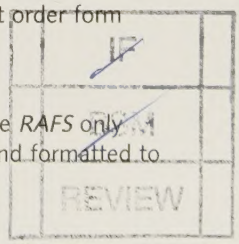

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